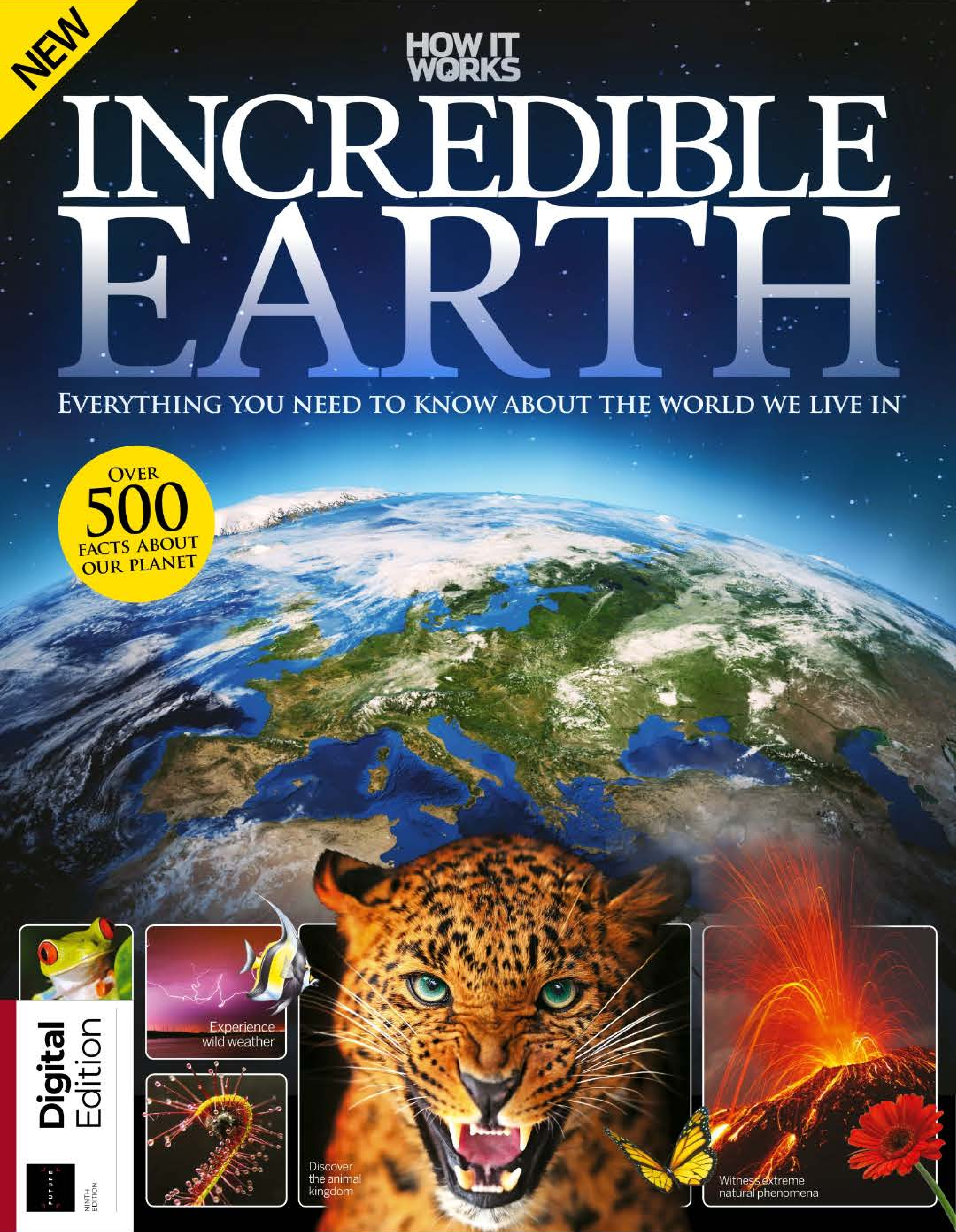

NEW

HOW IT WORKS

INCREDIBLE EARTH

EVERYTHING YOU NEED TO KNOW ABOUT THE WORLD WE LIVE IN

OVER 500 FACTS ABOUT OUR PLANET

Experience wild weather

Discover the animal kingdom

Witness extreme natural phenomena

Digital Edition

FUTURE

NINTH EDITION

Welcome to

HOW IT WORKS BOOK OF INCREDIBLE EARTH

The planet we live on is a remarkable place, with incredible things happening everywhere, all the time. But have you ever wondered how or why these things occur? How the Earth was created? How we predict the weather? How fossils form? What causes earthquakes? Which animals glow in the dark? The How It Works Book of Incredible Earth provides answers to all these questions and more as it takes you on a thrilling journey through everything you need to know about the world we live in. Covering the scientific explanations behind weather phenomena, poisonous plants, extreme landscapes and volatile volcanoes, as well as the amazing creatures found throughout the animal kingdom and in our homes, there is something for everyone to enjoy. Packed full of fascinating facts, gorgeous photography and insightful diagrams, the Book of Incredible Earth will show you just how awe-inspiring our planet really is.

HOW IT WORKS BOOK OF INCREDIBLE EARTH

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bookazine series

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© Scotto Bear

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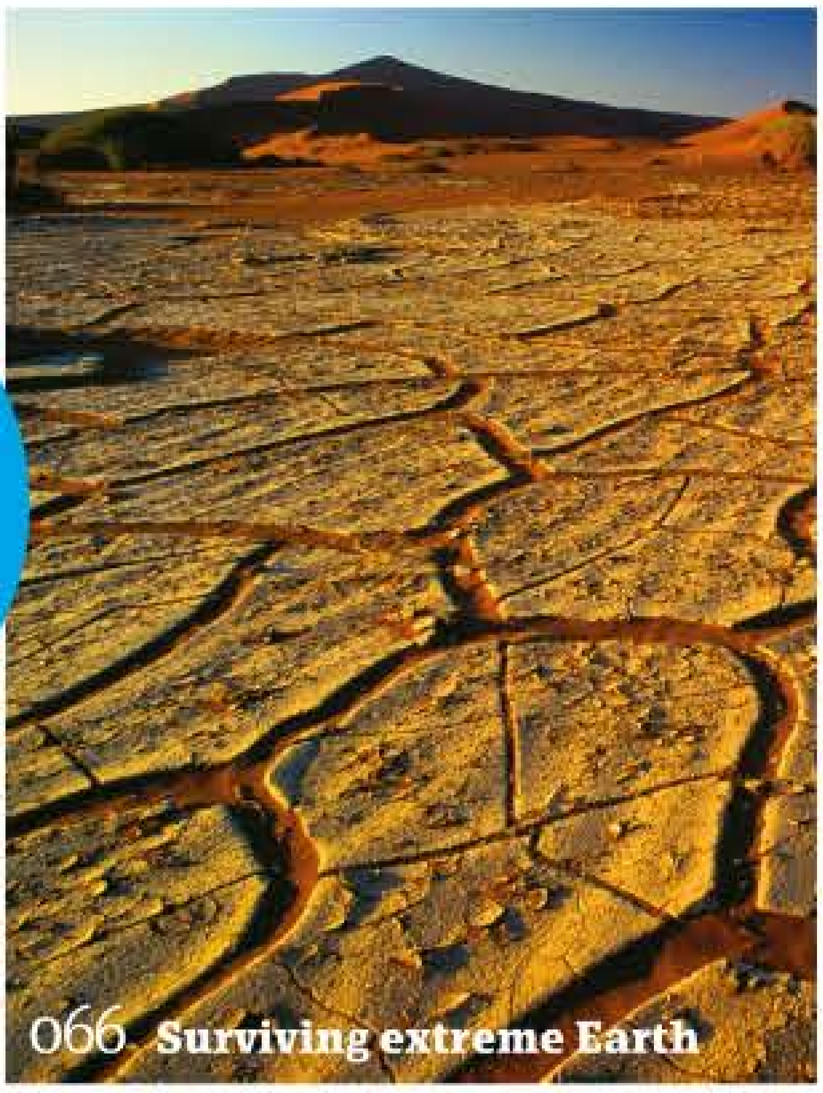

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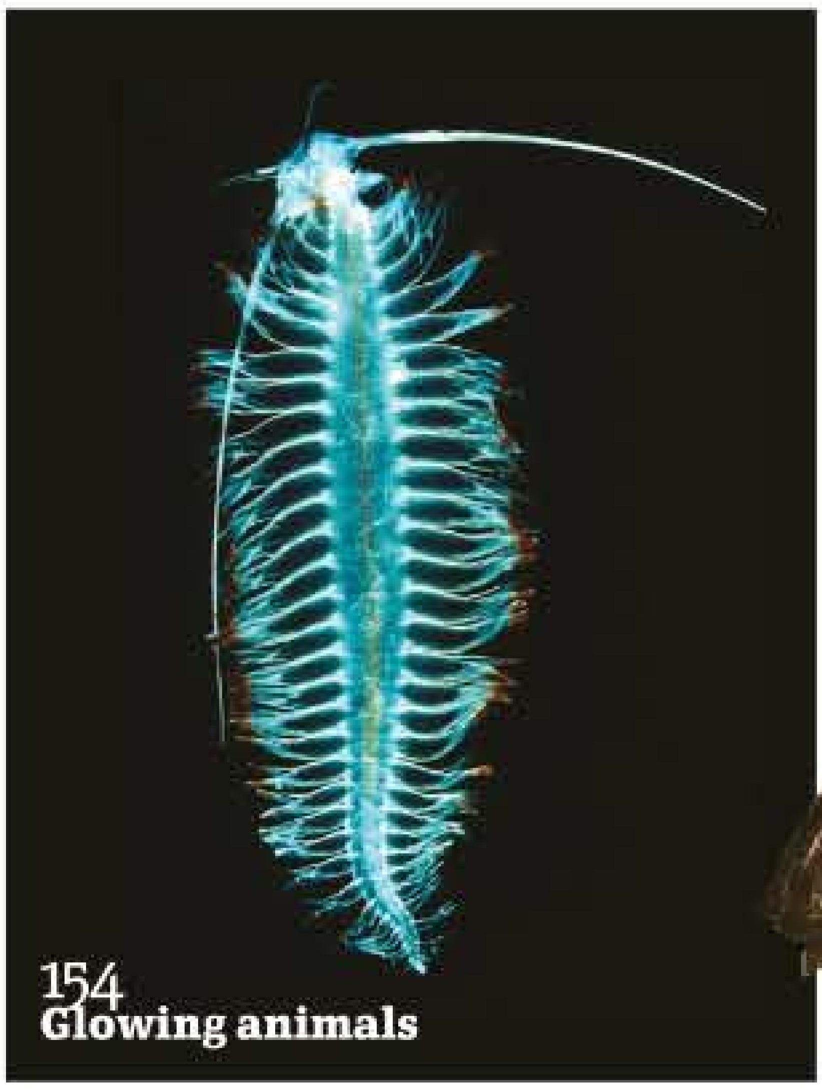

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© Peter Steen Leidersdorff

Wild encounters

Daring adventurer and wildlife enthusiast Steve Backshall discusses life on the edge

After a few years of living in the jungle, Steve Backshall earned the title 'Adventurer in Residence' for National Geographic Channel in 1998. He moved to the BBC in 2003, and has been making programmes about exploration and wildlife ever since. Backshall has come face-to-face with some of the planet's most fearsome predators. He confesses: "I am much more frightened in a big city on a Saturday night after pub closing time than I would be tracking lions on foot." Backshall is going on a UK tour to share stories and reveal some of the behind-the-scenes action from his expeditions. We spoke to him about survival tips, death-defying climbs and dancing with whales.

Your TV shows are edge-of-your-seat viewing, but what don't we see on screen?
The outtakes usually involve animals doing the opposite of what I want. There are countless examples of animals ignoring me, breaking wind in my face, snapping and snarling, and doing other things that you don't expect them to.

What is the most difficult part of your job?
I think the most difficult part is how long it can take to find particular animals. Some things I can go out and find without too much trouble. Other things take inordinate amounts of effort and patience, and it can start to get quite stressful knowing somehow you've got to film this show and you haven't found the animal yet.

Have there been any moments in your career where you've genuinely feared for your life?
The expedition involving the first ascent of Amaurai Tepui, a vertical, sandstone-sided mountain in Venezuela. It was the follow-on to the highly successful first ascent we'd done a few years before. We were really excited about it, and it ended up being much more dangerous than we thought. We had rock-fall tumbling around our ears, a massive storm that raged in. It was unsafe. Even the guys on the team, who are some of the best climbers in the world, were terrified.

What's the greatest discovery you've made?
I've been lucky enough to take the first light into cave systems that have never been explored, to make first ascents of mountains, first descents of white-water rivers, and to hold animals in my hand that are new to science. Perhaps the greatest of those was on the *Lost Land of the Volcano* expedition. We went to New Guinea with a team of scientists, and discovered as many as 20 new animals, including the world's largest species of giant rat, a new marsupial, a new bat and about ten new species of frog.

Do you have a bucket list of animals you want to see?
There are a lot of animals that I've put a huge amount of work into finding and still haven't seen. I've spent at least two months on the road looking for mountain lions and never seen one. I would love to go to the Karakoram in Pakistan to climb and look for snow leopards. That would be a dream. The longer I do this, the more I see what is left to do, and the bigger my list becomes.

What's the most beautiful thing in nature?
Probably free-diving alongside a female sperm whale, who was interacting with me, almost dancing with me, underwater. She was mirroring my movements, replicating the same somersaults I was doing and looking me in the eye the whole time. It was like dancing a ballet with an animal that must have weighed ten tons.

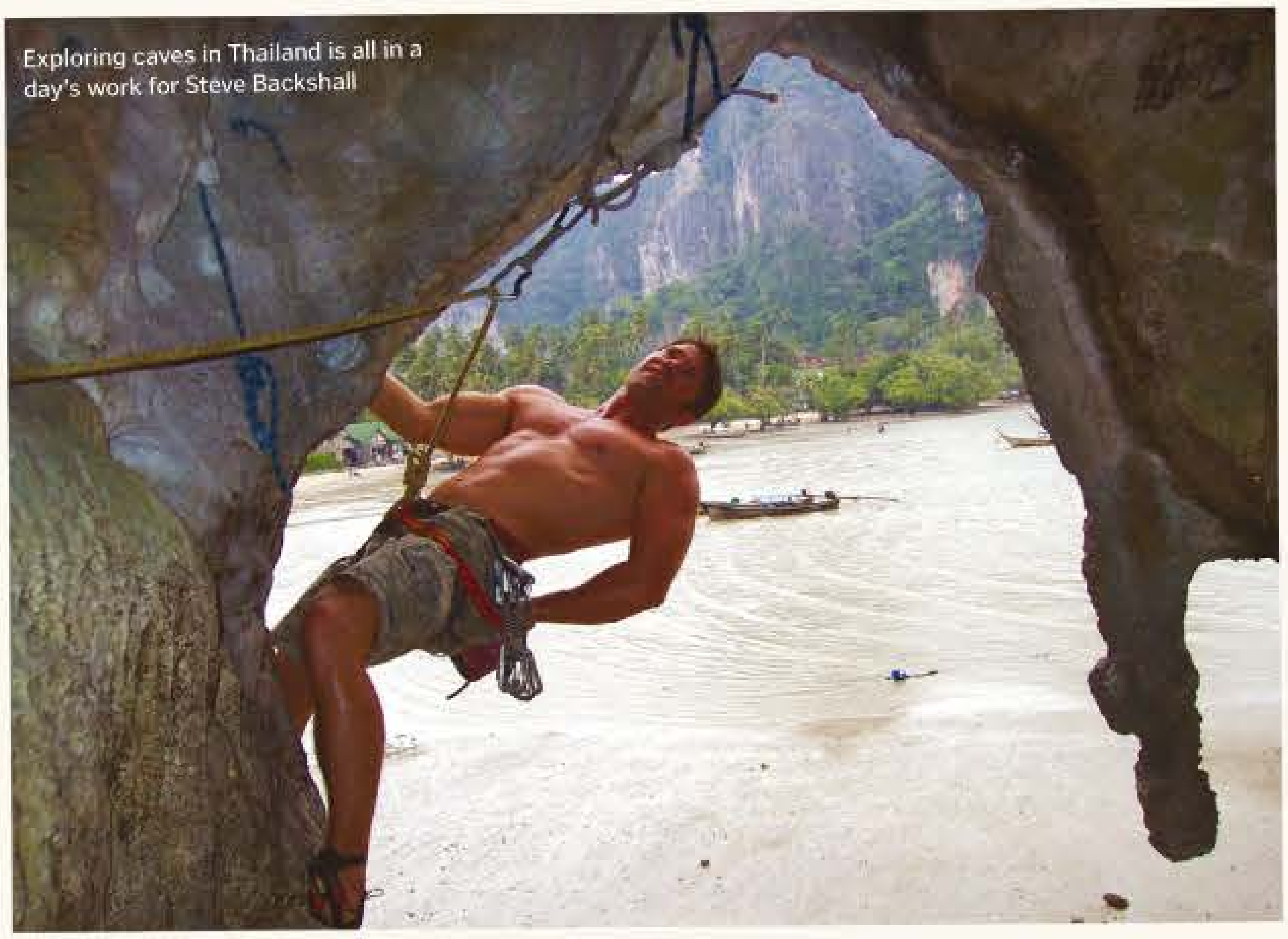
Close to extinction

As a dedicated ambassador for animal conservation, Steve Backshall reveals the three species disappearing from our planet faster than any others

Vultures
Numbers have plummeted since the 1980s due to the veterinary drug diclofenac. It's passed on to them when they eat the carcasses of animals that have been treated with the drug, and this causes kidney failure.

Frogs
The chytrid fungus is responsible for causing a global mass extinction of frogs. It infects a frog's skin, causing it to thicken and making it difficult for the animal to absorb the water and salts it needs to survive.

Sharks
The threat to sharks comes mainly from humans. Longlining, a technique for catching tuna, results in sharks getting hooked by accident. Fishermen will often then remove their fins to sell, due to the high demand for shark fin soup, a delicacy in Asia.



Exploring caves in Thailand is all in a day's work for Steve Backshall

Steve has wrestled with anacondas, vipers and cobras, but his only snakebite was from an adder in the UK

Steve has climbed some of the world's most dangerous mountains

What is the scariest animal on the planet?
The scariest is the hippo because it is so unpredictable. Snakes, scorpions and spiders almost have a set of rules for how they will behave in each situation. Hippos are much more intelligent than you might think, much faster and have a tendency to be aggressive as well, so that coupled with the fact that you don't know what they're going to do next makes them potentially the most dangerous animal to be around.

Where is your favourite place on Earth?
Probably the Himalayas. I get a chance to go back there quite often. It's a place where the grandeur and majesty of the landscape is phenomenal. It changes constantly throughout the day, week and year. It's a place with many unclimbed peaks and great challenges, so I love it.

What item of kit could you never miss?
Superglue. It was apparently developed in the Vietnam War for surgical use, and I still use it for that now. I apply it to blisters and minor cuts and it can also be used to hold together elements of your kit. It's one of the first things that I pack.

What useful survival tip have you received?
When you're working with predatory animals, never run. Predators, generally speaking, have learnt over generations to fear us human beings. If you encounter even potentially very dangerous animals, such as big cats, in the wild, the chances of them attacking you are close to zero, unless you run. The second you run, you are doing what prey does and their instincts kick in and they will chase you down and attack you. Stand still and you'll probably get away with it.

Any advice for aspiring adventurers?
Start small and close to home. Adventure begins in your own back yard. Learn about things you can find right here in the UK: the bugs and invertebrates that live in your garden. Particularly at this time of year, when it's warm, there will be plenty of things in your garden that you might not know about but have incredible, interesting lives.

INCREDIBLE STORY OF EARTH

Ancient and teeming with life, Earth is a truly amazing planet, with a fascinating tale to tell…

Today, science has revealed much about our planet, from how it formed and has evolved over billions of years through to its current position in the universe. Indeed, right now we have a clearer picture of Earth than ever before.

And what a terrifying and improbable picture it is. A massive spherical body of metal, rock, liquid and gas suspended perilously within a vast void by an invisible, binding force. It is a body that rotates continuously, is tilted on an axis by 23 degrees and orbits once every 365.256 solar days around a flaming ball of hydrogen 150 million kilometres (93 million miles) away. It is a celestial object that, on face value, is mind-bendingly unlikely.

As a result, the truth about our planet and its history eluded humans for thousands of years. Naturally, as beings that like to know the answers to *how* and *why*, we have come up with many ways to fill in the gaps. The Earth was flat; the Earth was the centre of the universe; and, of course, all manner of complex and fiercely defended beliefs about creation.

But then in retrospect, who could have ever guessed that our planet formed from specks of dust and mineral grains in a cooling gas cloud of a solar nebula? That the spherical Earth consists of a series of fluid elemental layers and plates around an iron-rich molten core? Or that our world is over 4.5 billion years old and counting? Only some of the brightest minds over many millennia could grant an insight into these geological realities.

While Earth may only be the fifth biggest planet in our Solar System, it is by far the most awe-inspiring. Perhaps most impressive of all, it's still reaffirming the fundamental laws that have governed the universe ever since the Big Bang. Here, we celebrate our world in all its glory, charting its journey from the origins right up to the present and what lies ahead.

> *"Earth is awe-inspiring… it's still reaffirming the fundamental laws that have governed the universe ever since the Big Bang"*

From dust to planet

To get to grips with how the Earth formed, first we need to understand how the Solar System as a whole developed – and from what. Current evidence suggests that the beginnings of the Solar System lay some 4.6 billion years ago with the gravitational collapse of a fragment of a giant molecular cloud.

In its entirety this molecular cloud – an interstellar mass with the size and density to form molecules like hydrogen – is estimated to have been 20 parsecs across, with the fragment just five per cent of that. The gravitationally induced collapse of this fragment resulted in a pre-solar nebula – a region of space with a mass slightly in excess of the Sun today and consisting primarily of hydrogen, helium and lithium gases generated by Big Bang nucleosynthesis (BBN).

At the heart of this pre-solar nebula, intense gravity – along with supernova-induced over-density within the core, high gas pressures, nebula rotation (caused by angular momentum) and fluxing magnetic fields – in conjunction caused it to contract and flatten into a protoplanetary disc. A hot, dense protostar formed at its centre, surrounded by a 200-astronomical-unit cloud of gas and dust.

It is from this solar nebula's protoplanetary disc that Earth and the other planets emerged. While the protostar would develop a core temperature and pressure to instigate hydrogen fusion over a period of approximately 50 million years, the cooling gas of the disc would produce mineral grains through condensation, which would amass into tiny meteoroids. The latest evidence indicates that the oldest of the meteoroidal material formed about 4.56 billion years ago.

As the dust and grains were drawn together to form ever-larger bodies of rock (first chondrules, then chondritic meteoroids), through continued accretion and collision-induced compaction, planetesimals and then protoplanets appeared – the latter being the precursor to all planets in the Solar System. In terms of the formation of Earth, the joining of multiple planetesimals meant it developed a gravitational attraction powerful enough to sweep up additional particles, rock fragments and meteoroids as it rotated around the Sun. The composition of these materials would, as we shall see over the page, enable the protoplanet to develop a superhot core.

Gathering meteoroids
Chondrites aggregated as a result of gravity and went on to capture other bodies. This led to an asteroid-sized planetesimal.

Dust and grains
Dust and tiny pieces of minerals orbiting around the T Tauri star impact one another and continue to coalesce into ever-larger chondritic meteoroids.

Fully formed
Over billions of years Earth's atmosphere becomes oxygen rich and, through a cycle of crustal formation and destruction, develops vast landmasses.

> "The collapse of this fragment resulted in a pre-solar nebula – a region of space with a mass slightly in excess of the Sun today"

The history of Earth

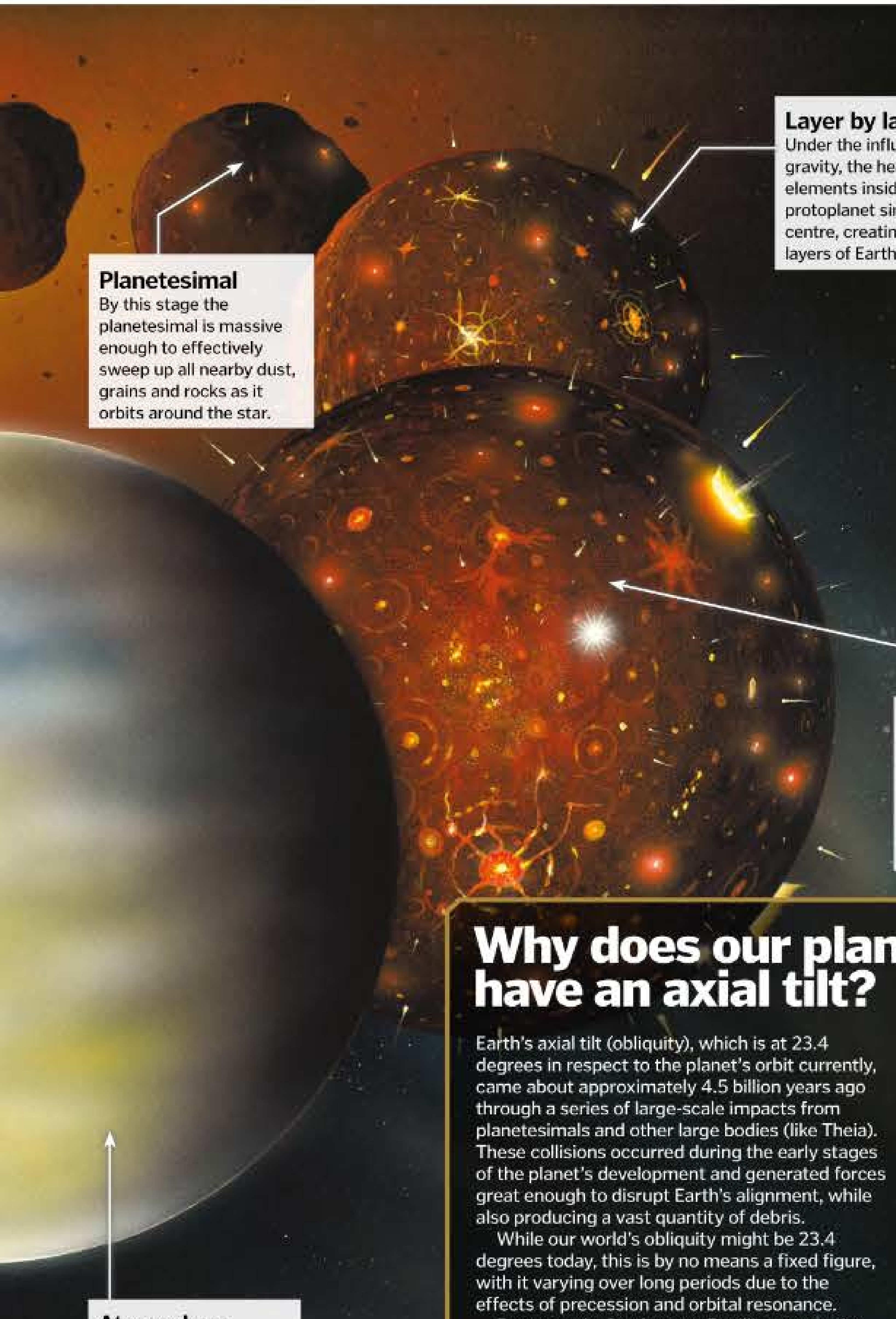
Follow the major milestones in our planet's epic development
***(BYA = billion years ago)**

13.8 BYA*

Big Bang fallout
Nucleosynthesis as a result of the Big Bang leads to the gradual formation of chemical elements on a huge scale.

4.6 BYA

New nebula
A fragment of a giant molecular cloud experiences a gravitational collapse and becomes a pre-solar nebula.



Layer by layer
Under the influence of gravity, the heavier elements inside the protoplanet sink to the centre, creating the major layers of Earth's structure.

Planetesimal
By this stage the planetesimal is massive enough to effectively sweep up all nearby dust, grains and rocks as it orbits around the star.

Growing core
Heated by immense pressure and impact events, the metallic core within grows. Activity in the mantle and crust heightens.

Atmosphere
Thanks to volcanic outgassing and ice deposition via impacts, Earth develops an intermediary carbon-dioxide rich atmosphere.

Origins of the Moon

Today most scientists believe Earth's sole satellite formed off the back of a collision event that occurred roughly 4.53 billion years ago. At this time, Earth was in its early development stage and had been impacted numerous times by planetesimals and other rocky bodies – events that had shock-heated the planet and brought about the expansion of its core.

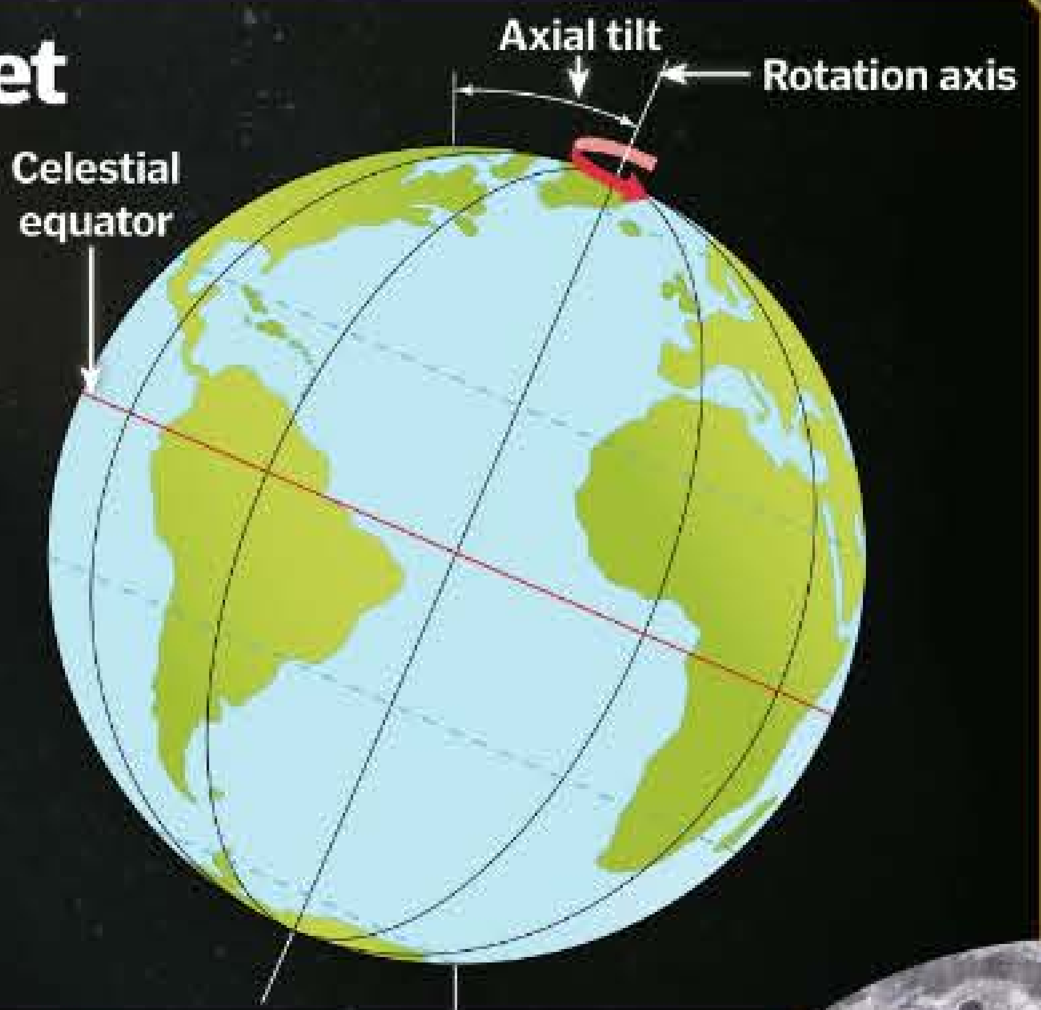
One collision, however, seems to have been a planet-sized body around the size of Mars – dubbed Theia. Basic models of impact data suggest Theia struck Earth at an oblique angle, with its iron core sinking into the planet, while its mantle, as well as that of Earth, was largely hurled into orbit. This ejected material – which is estimated to be roughly 20 per cent of Theia's total mass – went on to form a ring of silicate material around Earth and then coalesce within a relatively short period (ranging from a couple of months up to 100 years) into the Moon.

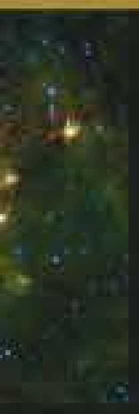
Why does our planet have an axial tilt?

Earth's axial tilt (obliquity), which is at 23.4 degrees in respect to the planet's orbit currently, came about approximately 4.5 billion years ago through a series of large-scale impacts from planetesimals and other large bodies (like Theia). These collisions occurred during the early stages of the planet's development and generated forces great enough to disrupt Earth's alignment, while also producing a vast quantity of debris.

While our world's obliquity might be 23.4 degrees today, this is by no means a fixed figure, with it varying over long periods due to the effects of precession and orbital resonance.

For example, for the past 5 million years, the axial tilt has varied from 22.2-24.3 degrees, with a mean period lasting just over 41,000 years. Interestingly, the obliquity would be far more variable if it were not for the presence of the Moon, which has a stabilising effect.





4.57 BYA

Protostar
Several million years later, the precursor to the Sun (a T Tauri-type star) emerges at the heart of the nebula.

4.56 BYA

Disc develops
Around the T Tauri star a protoplanetary disc of dense gas begins to form and then gradually cools.

4.54 BYA

Planet
As dust and rock gather, Earth becomes a planet, with planetary differentiation leading to the core's formation.

4.53 BYA

Birth of the Moon
Theia, a Mars-sized body, impacts with the Earth. The resulting debris rises into orbit and will coalesce into the Moon.

Earth's structure

As the mass of the Earth continued to grow, so did its internal pressure. This in partnership with the force of gravity and 'shock heating' – see boxout opposite for an explanation – caused the heavier metallic minerals and elements within the planet to sink to its centre and melt. Over many years, this resulted in the development of an iron-rich core and, consequently, kick-started the interior convection which would transform our world.

Once the centre of Earth was hot enough to convect, planetary differentiation began. This is the process of separating out different elements of a planetary body through both physical and chemical actions. Simply put, the denser materials of the body sink towards the core and the less dense rise towards the surface. In Earth's case, this would eventually lead to the distinct layers of inner core, outer core, mantle and crust – the latter developed largely through outgassing.

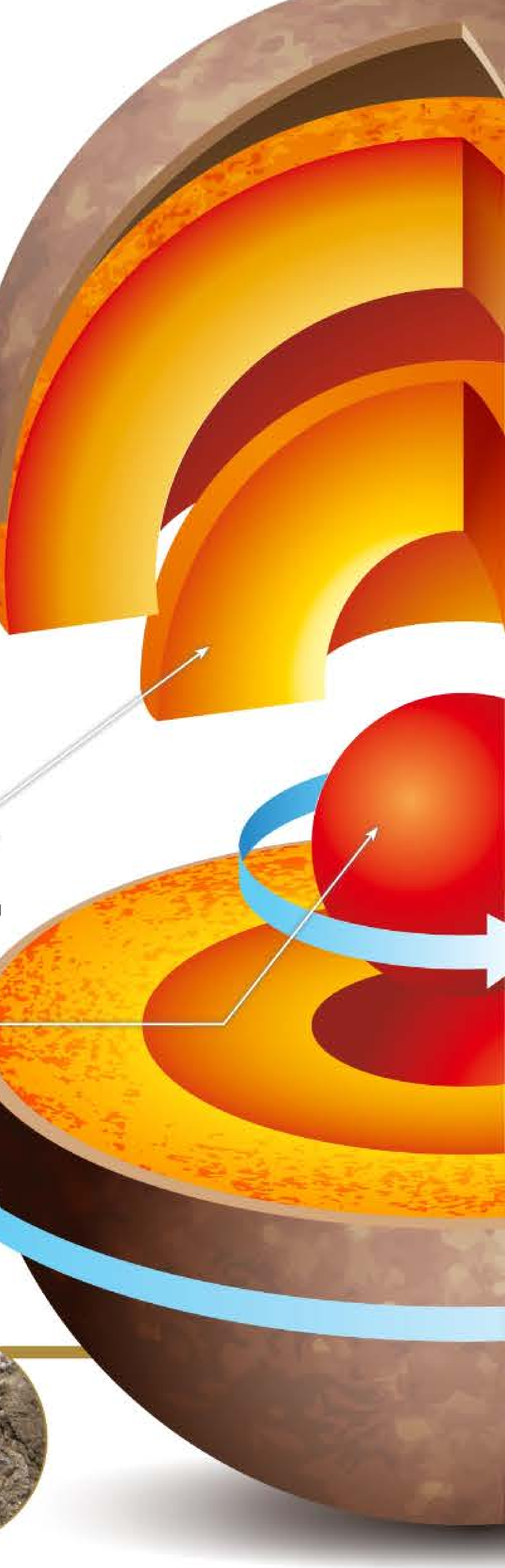
Outgassing in Earth occurred when volatile substances located in the lower mantle began to melt approximately 4.3 billion years ago. This partial melting of the interior caused chemical separation, with resulting gases rising up through the mantle to the surface, condensing and then crystallising to form the first crustal layer. This original crust proceeded to go through a period of recycling back into the mantle through convection currents, with successive outgassing gradually forming thicker and more distinct crustal layers.

The precise date when Earth gained its first complete outer crust is unknown, as due to the recycling process only incredibly small parts of it remain today. Certain evidence, however, indicates that a proper crust was formed relatively early in the Hadean eon (4.6-4 billion years ago). The Hadean eon on Earth was characterised by a highly unstable, volcanic surface (hence the name 'Hadean', derived from the Greek god of the underworld, Hades). Convection currents from the planet's mantle would elevate molten rock to the surface, which would either revert to magma or harden into more crust.

Scientific evidence suggests that outgassing was also the primary contributor to Earth's first atmosphere, with a large region of hydrogen and helium escaping – along with ammonia, methane and nitrogen – considered the main factor behind its initial formation.

By the close of the Hadean eon, planetary differentiation had produced an Earth that, while still young and inhospitable, possessed all the ingredients needed to become a planet capable of supporting life.

But for anything organic to develop, it first needed water...



Outer core

Unlike the inner core, Earth's outer core is not solid but liquid, due to less pressure. It is composed of iron and nickel and ranges in temperature from 4,400°C (7,952°F) at its outer ranges to 6,100°C (11,012°F) at its inner boundary. As a liquid, its viscosity is estimated to be ten times that of liquid metals on the surface. The outer core was formed by only partial melting of accreted metallic elements.

Inner core

The heaviest minerals and elements are located at the centre of the planet in a solid, iron-rich heart. The inner core has a radius of 1,220km (760mi) and has the same surface temperature as the Sun (around 5,430°C/9,800°F). The solid core was created due to the effects of gravity and high pressure during planetary accretion.

> *"Outgassing occurred when volatile substances in the lower mantle began to melt 4.3 billion years ago"*

4.4 BYA

Surface hardens

Earth begins developing its progenitor crust. This is constantly recycled and built up through the Hadean eon.

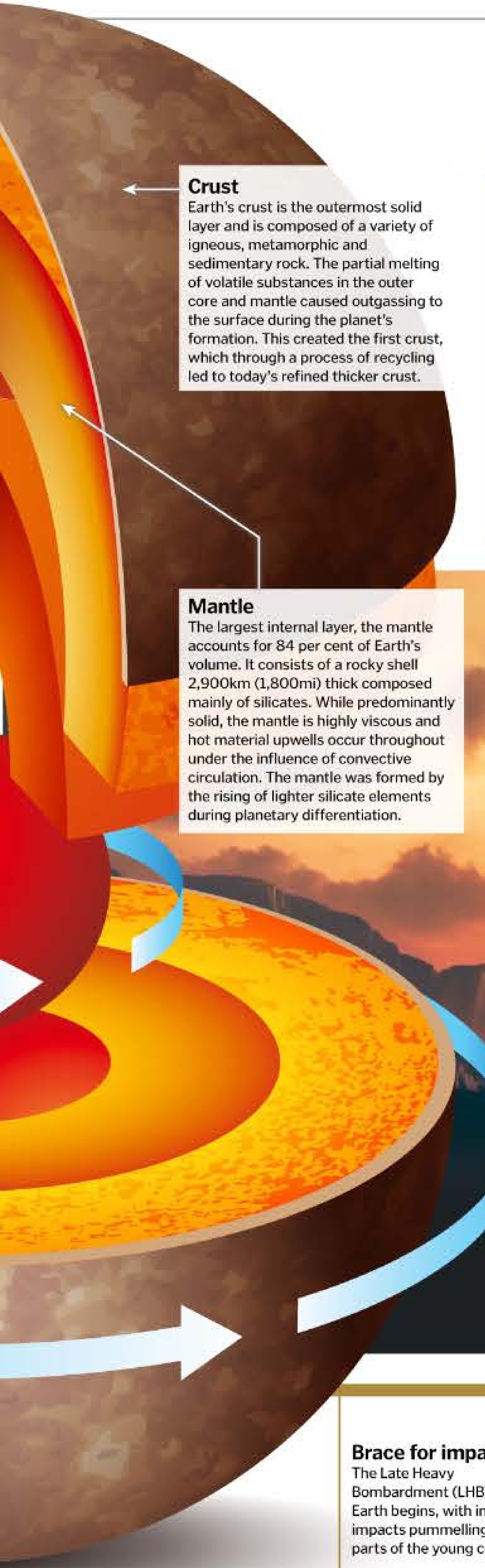
Early atmosphere

Outgassing and escaping gases from surface volcanism form the first atmosphere around the planet. It is nitrogen heavy.

4.28 BYA

Ancient rocks

A number of rocks have been found in northern Québec, Canada, that date from this period. They are volcanic deposits.



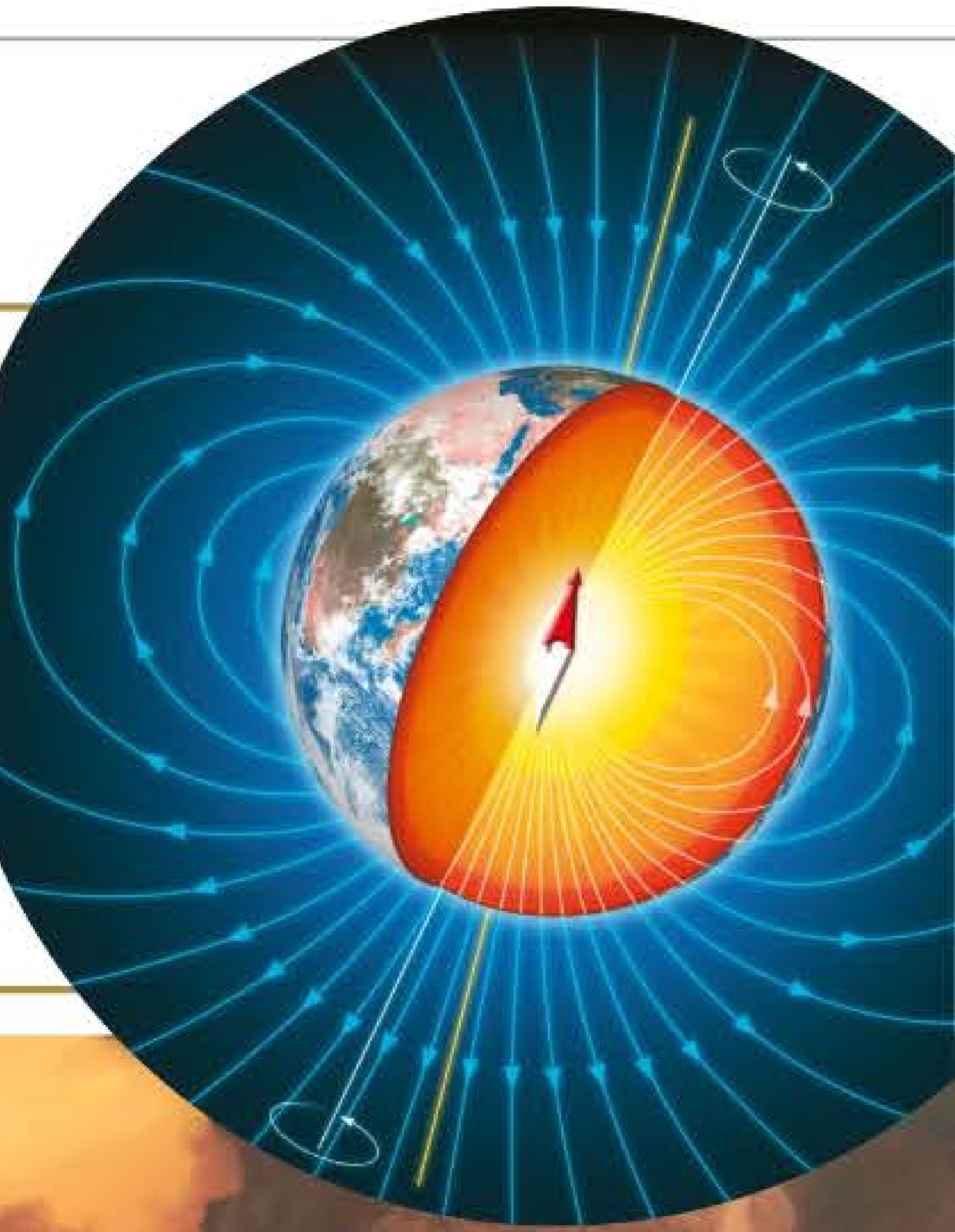
Crust

Earth's crust is the outermost solid layer and is composed of a variety of igneous, metamorphic and sedimentary rock. The partial melting of volatile substances in the outer core and mantle caused outgassing to the surface during the planet's formation. This created the first crust, which through a process of recycling led to today's refined thicker crust.

Mantle

The largest internal layer, the mantle accounts for 84 per cent of Earth's volume. It consists of a rocky shell 2,900km (1,800mi) thick composed mainly of silicates. While predominantly solid, the mantle is highly viscous and hot material upwells occur throughout under the influence of convective circulation. The mantle was formed by the rising of lighter silicate elements during planetary differentiation.

Magnetic field in the making



Earth's geomagnetic field began to form as soon as the young planet developed an outer core. The outer core of Earth generates helical fluid motions within its electrically conducting molten iron due to current loops driven by convection. As a result, the moment that convection became possible in Earth's core it began to develop a geomagnetic field – which in turn was amplified by the planet's rapid spin rate. Combined, these enabled Earth's magnetic field to permeate its entire body as well as a small region of space surrounding it – the magnetosphere.

Shock heating explained

During the accretion to its present size, Earth was subjected to a high level of stellar impacts by space rocks and other planetesimals too. Each of these collisions generated the effect of shock heating, a process in which the impactor and resultant shock wave transferred a great deal of energy into the forming planet. For meteorite-sized bodies, the vast majority of this energy was transferred across the planet's surface or radiated back off into space, however in the case of much larger planetesimals, their size and mass allowed for deeper penetration into the Earth. In these events the energy was distributed directly into the planet's inner body, heating it well beneath the surface. This heat influx contributed to heavy metallic fragments deep underground melting and sinking towards the core.

Brace for impact

The Late Heavy Bombardment (LHB) of Earth begins, with intense impacts pummelling many parts of the young crust.

4 BYA

Archean

The Hadean eon finally comes to an end and the new Archean period begins.

3.9 BYA

Ocean origins

Earth is now covered with liquid oceans due to the release of trapped water from the mantle and from asteroid/comet deposition.

3.6 BYA

Supercontinent

Our world's very first supercontinent, Vaalbara, begins to emerge from a series of combining cratons.

Supercontinent development

Where did the earliest landmasses come from and how did they change over time?

It started with Vaalbara...

Approximately 3.6 billion years ago, Earth's first supercontinent – Vaalbara – formed through the joining of several large continental plates. Data derived from parts of surviving cratons from these plates – eg the South African Kaapvaal and Australian Pilbara; hence 'Vaal-bara' – show similar rock records through the Archean eon, indicating that, while now separated by many miles of ocean, they once were one. Plate tectonics, which were much fiercer at this time, drove these plates together and also were responsible for separating them 2.8 billion years ago.

Kenor

Believed to have formed in the later part of the Archean eon 2.7 BYA, Kenor was the next supercontinent to form after Vaalbara. It developed through the accretion of Neoarchean cratons and a period of spiked continental crust formation driven by submarine magmatism. Kenor was broken apart by tectonic magma-plume rifting around 2.45 BYA.

Formation of land and sea

Current scientific evidence suggests that the formation of liquid on Earth was, not surprisingly, a complex process. Indeed, when you consider the epic volcanic conditions of the young Earth through the Hadean eon, it's difficult to imagine exactly how the planet developed to the extent where today 70 per cent of its surface is covered with water. The answer lies in a variety of contributory processes, though three can be highlighted as pivotal.

The first of these was a drop in temperature throughout the late-Hadean and Archean eons. This cooling caused outgassed volatile substances to form an atmosphere around the planet – see the opposite boxout for more details – with sufficient pressure for retaining liquids. This outgassing also transferred a large quantity of water that was trapped in the planet's internal accreted material to the surface. Unlike previously, now pressurised and trapped by the developing atmosphere, it began to condense and settle on the surface rather than evaporate into space.

The second key liquid-generating process was the large-scale introduction of comets and water-rich meteorites to the Earth during its formation and the Late Heavy Bombardment period. These frequent impact events would cause the superheating and vaporisation of many trapped minerals, elements and ices, which then would have been adopted by the atmosphere, cooled over time, condensed and re-deposited as liquid on the surface.

The third major contributor was photodissociation – which is the separation of substances through the energy of light. This process caused water vapour in the developing upper atmosphere to separate into molecular hydrogen and molecular oxygen, with the former escaping the planet's influence. In turn, this led to an increase in the partial pressure of oxygen on the planet's surface, which through its interactions with surface materials gradually elevated vapour pressure to a level where yet more water could form.

The combined result of these processes – as well as others – was a slow buildup of liquid

> *"This erosion of Earth's crustal layer aided the distinction of cratons – the base for some of the first continental landmasses"*

3.5 BYA

Early bacteria

Evidence suggests that the earliest primitive life forms – bacteria and blue-green algae – begin to emerge in Earth's growing oceans at this time.

3.3 BYA

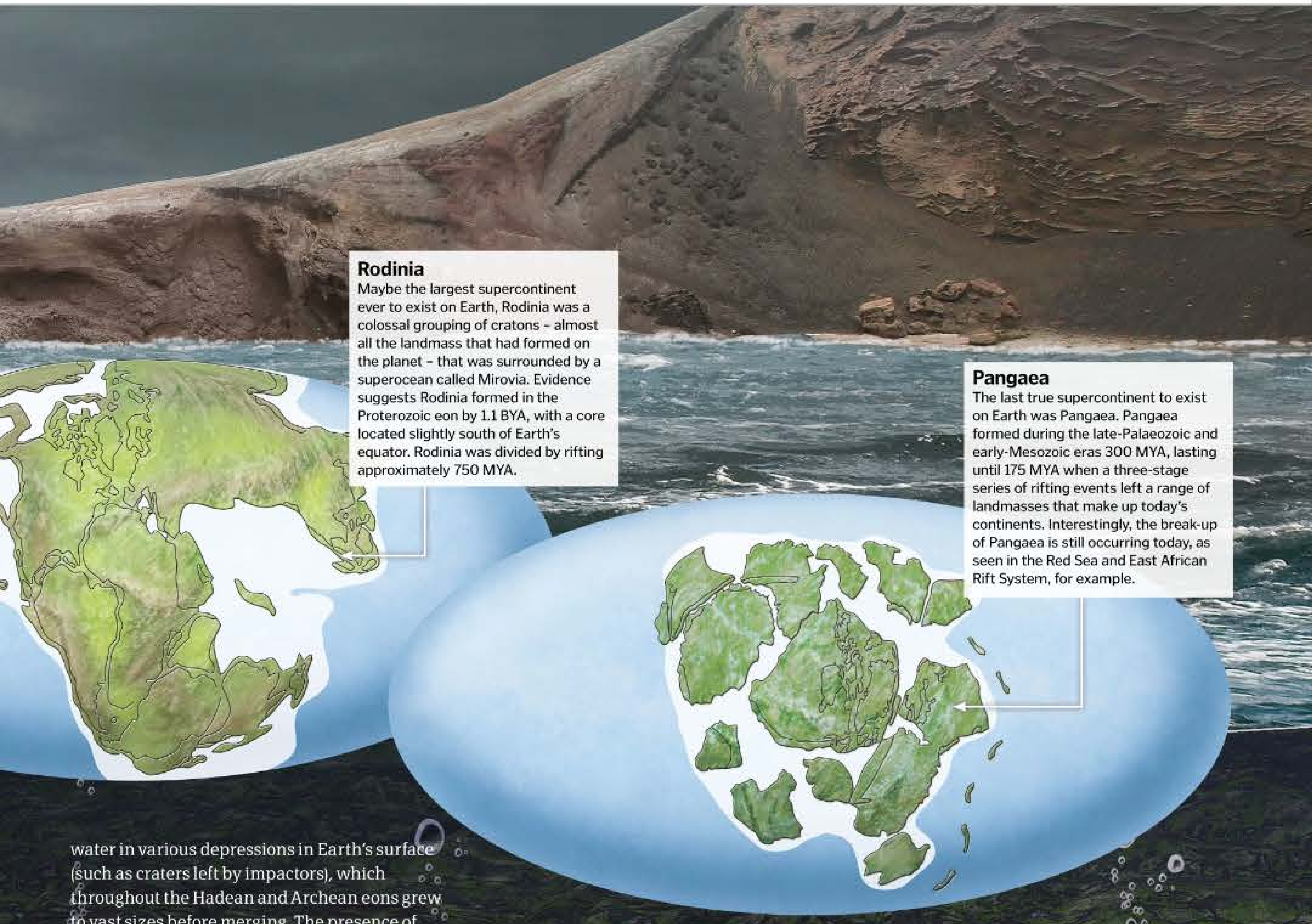
Hadean discovery

Sedimentary rocks have been found in Australia that date from this time. They contain zircon grains with isotopic ages between 4.4 and 4.2 BYA.

2.9 BYA

Island boom

The formation of island arcs and oceanic plateaux undergoes a dramatic increase that will last for about another 200 million years.



Rodinia
Maybe the largest supercontinent ever to exist on Earth, Rodinia was a colossal grouping of cratons – almost all the landmass that had formed on the planet – that was surrounded by a superocean called Mirovia. Evidence suggests Rodinia formed in the Proterozoic eon by 1.1 BYA, with a core located slightly south of Earth's equator. Rodinia was divided by rifting approximately 750 MYA.

Pangaea
The last true supercontinent to exist on Earth was Pangaea. Pangaea formed during the late-Palaeozoic and early-Mesozoic eras 300 MYA, lasting until 175 MYA when a three-stage series of rifting events left a range of landmasses that make up today's continents. Interestingly, the break-up of Pangaea is still occurring today, as seen in the Red Sea and East African Rift System, for example.

water in various depressions in Earth's surface (such as craters left by impactors), which throughout the Hadean and Archean eons grew to vast sizes before merging. The presence of extensive carbon dioxide in the atmosphere also caused the acidulation of these early oceans, with their acidity allowing them to erode parts of the surface crust and so increase their overall salt content. This erosion of Earth's crustal layer also aided the distinction of cratons – stable parts of the planet's continental lithosphere – which were the base for some of the first continental landmasses.

With liquid on the surface, a developing atmosphere, warm but cooling crust and continents starting to materialise, by the mid-Archean (approximately 3.5 billion years ago) conditions were ripe for life, which we look at in depth over the next couple of pages.

A closer look at Earth's evolving atmosphere

Earth has technically had three atmospheres throughout its existence. The first formed during the planet's accretion period and consisted of atmophile elements, such as hydrogen and helium, acquired from the solar nebula. This atmosphere was incredibly light and unstable and deteriorated quickly – in geological terms – by solar winds and heat emanating from Earth. The second atmosphere, which developed through the late-Hadean and early-Archean eons due to impact events and outgassing of volatile gases through volcanism, was anoxic – with high levels of greenhouse gases like carbon dioxide and very little oxygen. This second atmosphere later evolved during the mid-to-late-Archean into the third oxygen-rich atmosphere that is still present today. This oxygenation of the atmosphere was driven by rapidly emerging oxygen-producing algae and bacteria on the surface – Earth's earliest forms of life.

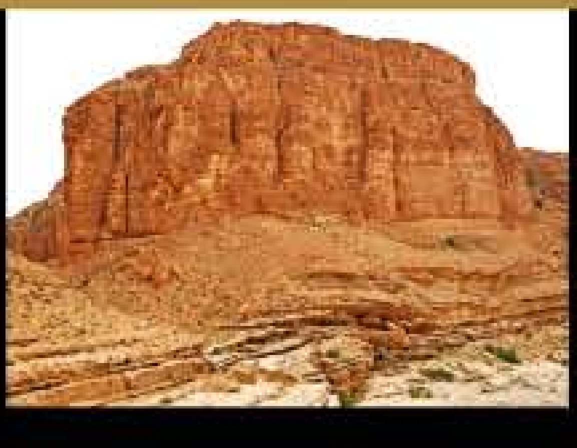
2.8 BYA
Breakup
After fully forming circa 3.1 BYA, Vaalbara begins to fragment due to the asthenosphere overheating.

2.5 BYA
Proterozoic
The Archean eon finally draws to a close after roughly 1.5 billion years, leading to the beginning of the Proterozoic era.

2.4 BYA
More oxygen
The Earth's atmosphere evolves into one that is rich in oxygen due to cyanobacterial photosynthesis.

2.1 BYA
Eukaryotes
Eukaryotic cells appear. These most likely developed by prokaryotes consuming each other via phagocytosis.

1.8 BYA
Red beds
Many of Earth's red beds – ferric oxide-containing sedimentary rocks – date from this period, indicating that an oxidising atmosphere was present.



The development of life

Of all the aspects of Earth's development, the origins of life are perhaps the most complex and controversial. That said, there's one thing upon which the scientific community as a whole agrees: that according to today's evidence, the first life on Earth would have been almost inconceivably small-scale.

There are two main schools of thought for the trigger of life: an RNA-first approach and a metabolism-first approach. The RNA-first hypothesis states that life began with self-replicating ribonucleic acid (RNA) molecules, while the metabolism-first approach believes it all began with an ordered sequence of chemical reactions, ie a chemical network.

Ribozymes are RNA molecules that are capable of both triggering their own replication and also the construction of proteins – the main building blocks and working molecules in cells. As such, ribozymes seem good candidates for the starting point of all life. RNA is made up of nucleotides, which are biological molecules composed of a nucleobase (a nitrogen compound), five-carbon sugar and phosphate groups (salts). The presence of these chemicals and their fusion is the base for the RNA-world theory, with RNA capable of acting as a less stable version of DNA.

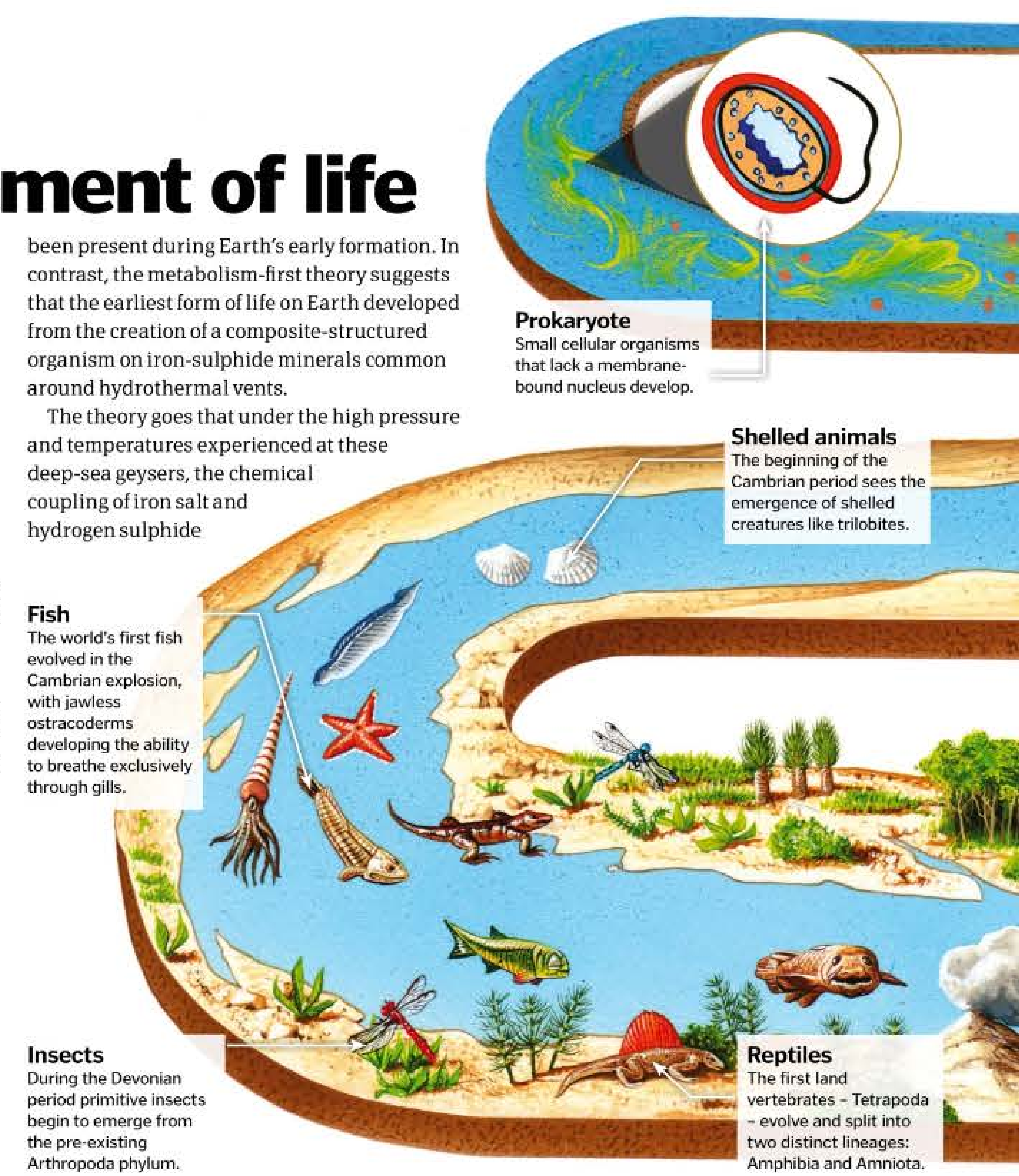
This theory begs two questions: one, were these chemicals present in early Earth and, two, how were they first fused? Until recently, while some success has been achieved in-vitro showing that activated ribonucleotides can polymerise (join) to form RNA, the key issue in replicating this formation was showing how ribonucleotides could form from their constituent parts (ie ribose and nucleobases).

Interestingly in a recent experiment reported in *Nature*, a team showed that pyrimidine ribonucleobases can be formed in a process that bypasses the fusion of ribose and nucleobases, passing instead through a series of other processes that rely on the presence of other compounds, such as cyanoacetylene and glycolaldehyde – which are believed to have been present during Earth's early formation. In contrast, the metabolism-first theory suggests that the earliest form of life on Earth developed from the creation of a composite-structured organism on iron-sulphide minerals common around hydrothermal vents.

The theory goes that under the high pressure and temperatures experienced at these deep-sea geysers, the chemical coupling of iron salt and hydrogen sulphide produced a composite structure with a mineral base and a metallic centre (such as iron or zinc).

The presence of this metal, it is theorised, triggered the conversion of inorganic carbon into organic compounds and kick-started constructive metabolism (forming new molecules from a series of simpler units). This process became self-sustaining by the generation of a sulphur-dependent metabolic cycle. Over time the cycle expanded and became more efficient, while simultaneously producing ever-more complex compounds, pathways and reaction triggers.

As such, the metabolism-first approach describes a system in which no cellular components are necessary to form life; instead, it started with a compound such as pyrite – a mineral which was abundant in early Earth's oceans. When considering that the oceans during the Hadean and early-Archean eons were extremely acidic – and that the planet's overall temperature was still very high –



Prokaryote
Small cellular organisms that lack a membrane-bound nucleus develop.

Shelled animals
The beginning of the Cambrian period sees the emergence of shelled creatures like trilobites.

Fish
The world's first fish evolved in the Cambrian explosion, with jawless ostracoderms developing the ability to breathe exclusively through gills.

Insects
During the Devonian period primitive insects begin to emerge from the pre-existing Arthropoda phylum.

Reptiles
The first land vertebrates – Tetrapoda – evolve and split into two distinct lineages: Amphibia and Amniota.

1.4 BYA
Fungi
The earliest signs of fungi according to current fossil evidence suggest they developed here in the Proterozoic.

1.2 BYA
Reproduction
With the dawn of sexual reproduction, the rate of evolution increases rapidly and exponentially.

542 MYA
Explosion
The Cambrian explosion occurs – a rapid diversification of organisms that leads to the development of most modern phyla (groups).

541 MYA
Phanerozoic
The Proterozoic eon finally draws to a close and the current geologic eon – the Phanerozoic – commences.

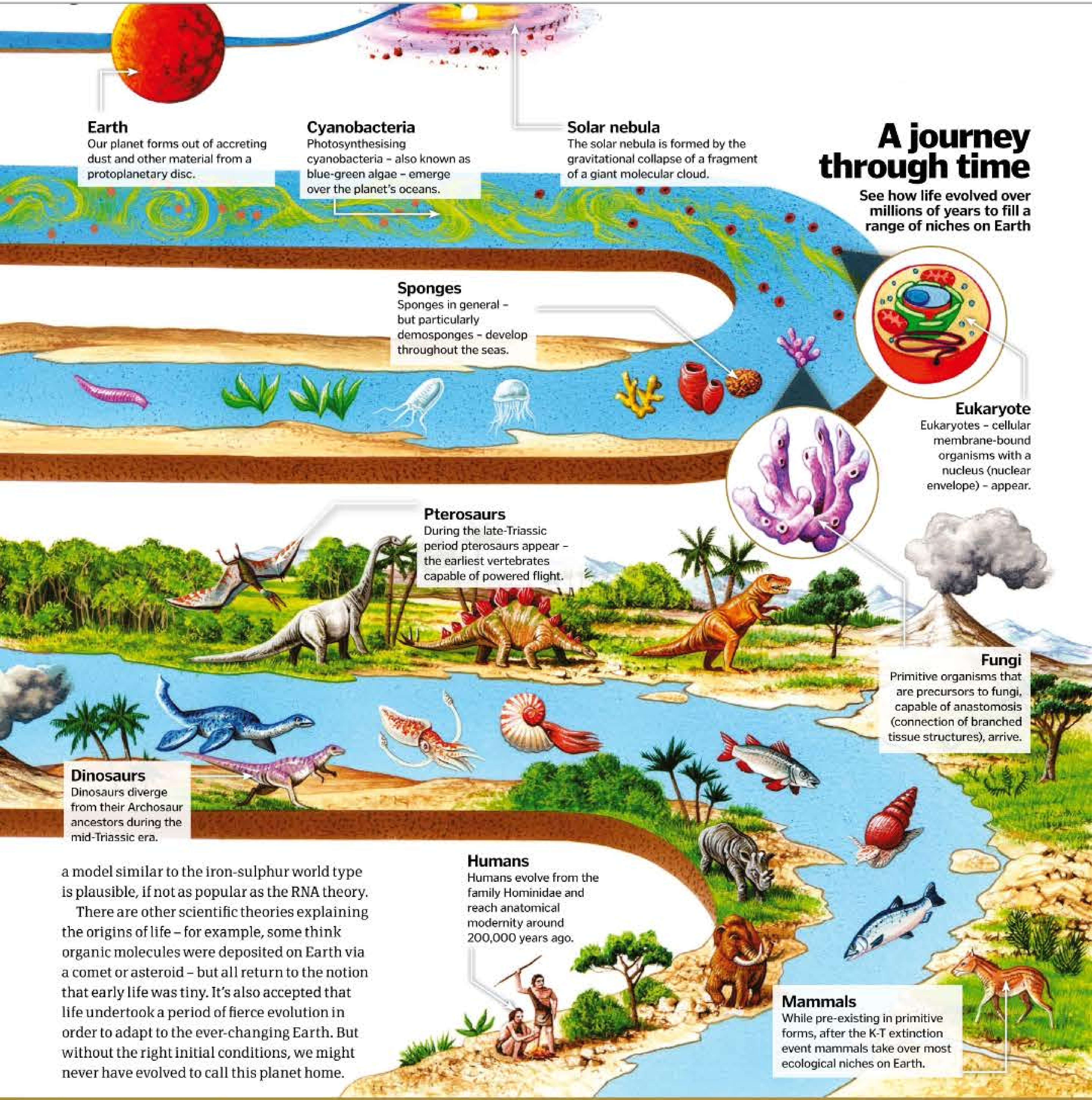
106 MYA
Spinosaurus
The largest theropod dinosaur ever to live on Earth, weighing up to an astonishing 20 tons, emerges at this time.

a model similar to the iron-sulphur world type is plausible, if not as popular as the RNA theory.

There are other scientific theories explaining the origins of life – for example, some think organic molecules were deposited on Earth via a comet or asteroid – but all return to the notion that early life was tiny. It's also accepted that life undertook a period of fierce evolution in order to adapt to the ever-changing Earth. But without the right initial conditions, we might never have evolved to call this planet home.

A journey through time

See how life evolved over millions of years to fill a range of niches on Earth



Earth
Our planet forms out of accreting dust and other material from a protoplanetary disc.

Cyanobacteria
Photosynthesising cyanobacteria – also known as blue-green algae – emerge over the planet's oceans.

Solar nebula
The solar nebula is formed by the gravitational collapse of a fragment of a giant molecular cloud.

Sponges
Sponges in general – but particularly demosponges – develop throughout the seas.

Eukaryote
Eukaryotes – cellular membrane-bound organisms with a nucleus (nuclear envelope) – appear.

Pterosaurs
During the late-Triassic period pterosaurs appear – the earliest vertebrates capable of powered flight.

Fungi
Primitive organisms that are precursors to fungi, capable of anastomosis (connection of branched tissue structures), arrive.

Dinosaurs
Dinosaurs diverge from their Archosaur ancestors during the mid-Triassic era.

Humans
Humans evolve from the family Hominidae and reach anatomical modernity around 200,000 years ago.

Mammals
While pre-existing in primitive forms, after the K-T extinction event mammals take over most ecological niches on Earth.

65.5 MYA
K-T event
The Cretaceous-Palaeogene extinction event occurs, wiping out half of all animal species on Earth, including the dinosaurs.

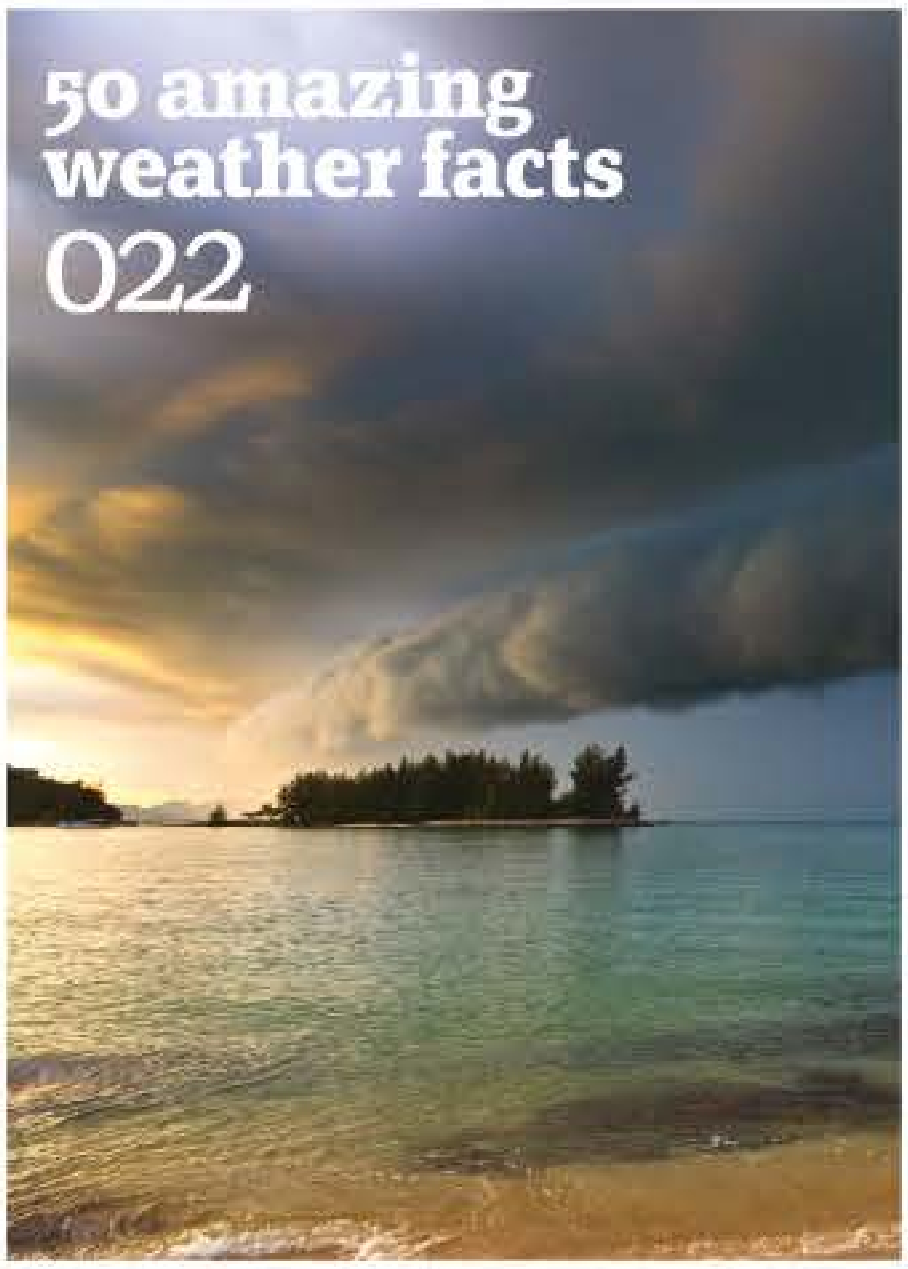
55 MYA
Birds take off
Bird groups begin to diversify dramatically, with many species still around today – such as parrots.

2 MYA
Homo genus
The first members of the genus Homo, of which humans are members appear in the fossil record.

350,000 years ago
Neanderthal
Neanderthals evolve and spread across Eurasia. They become extinct 220,000 years later.

200,000 years ago
First human
Anatomically modern humans evolve in Africa; 150,000 years later they start to move farther afield.

WEATHER WONDERS



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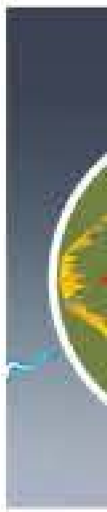
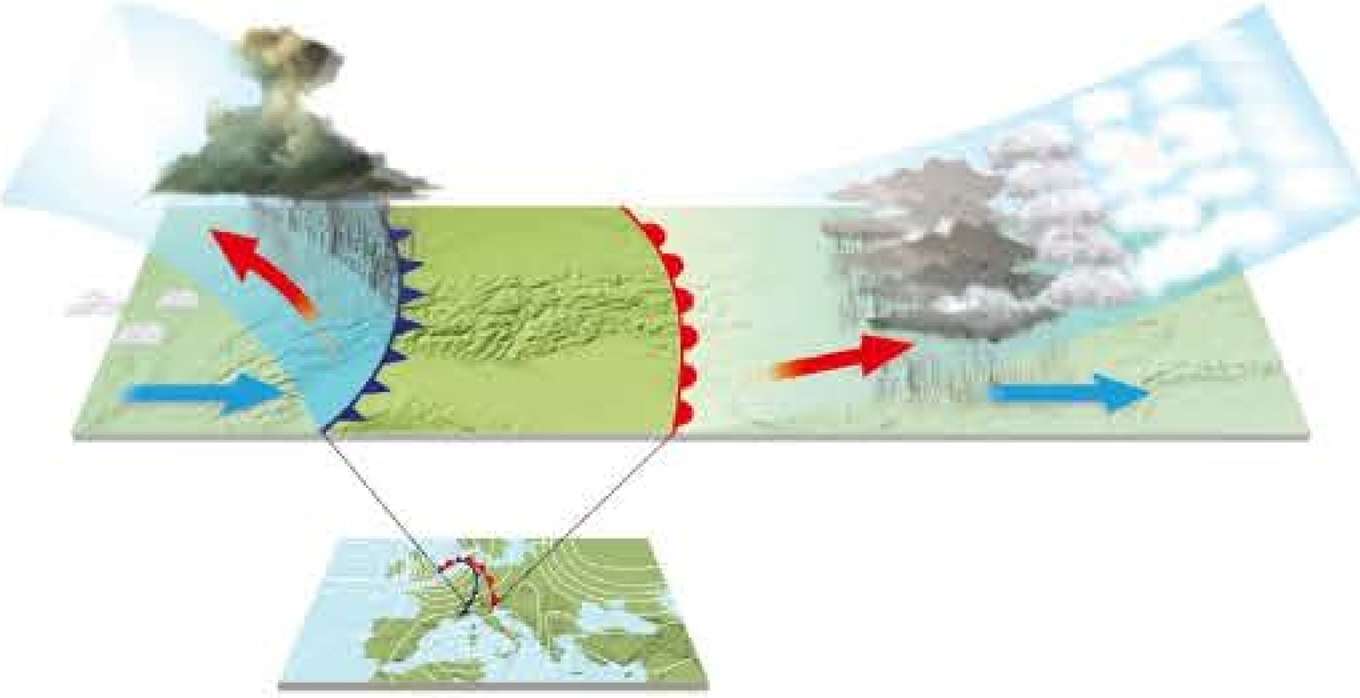
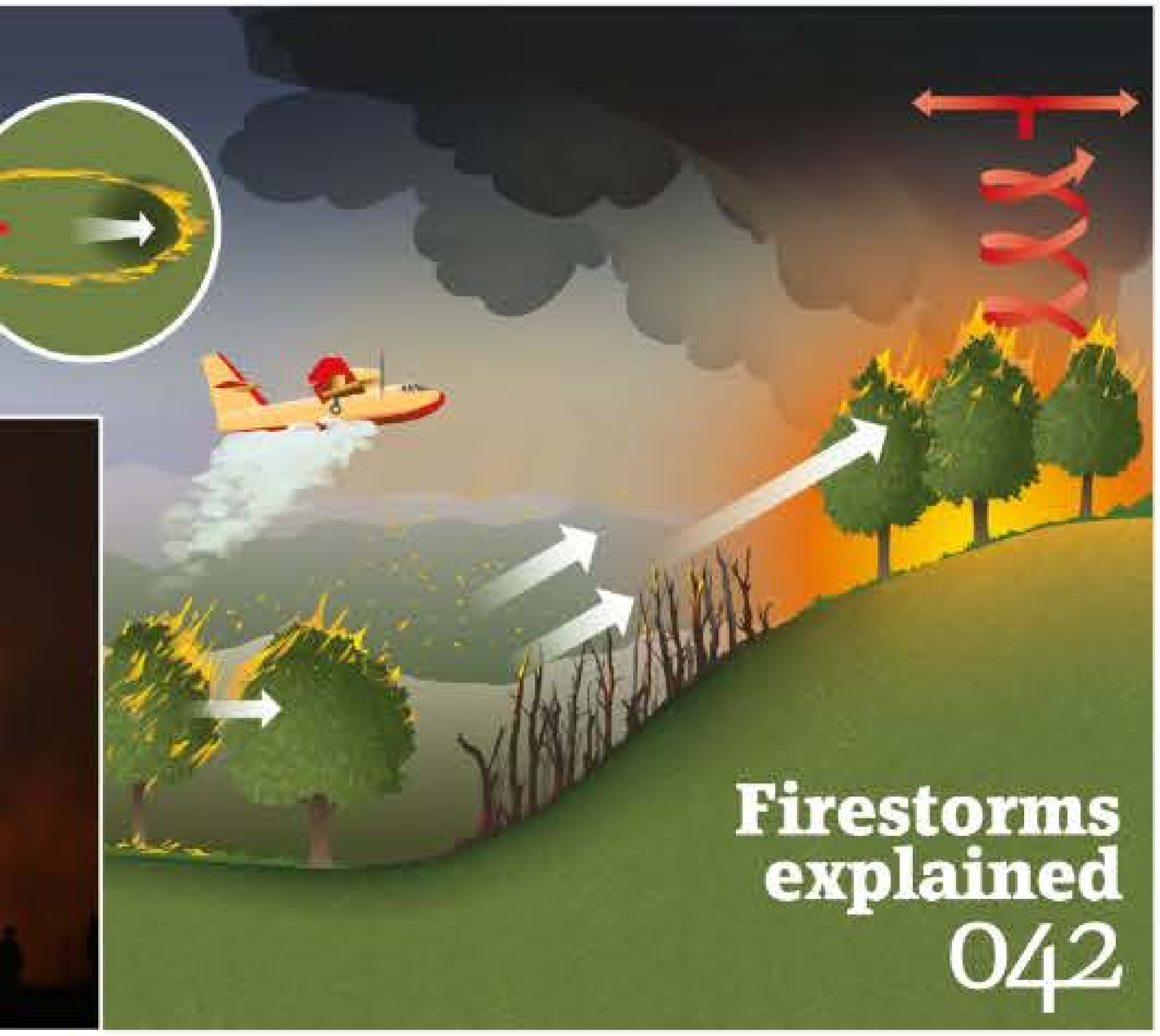


How do we predict the weather?

036





Firestorms explained

042

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Why does rain smell?

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50 AMAZING FACTS ABOUT WEATHER

How many lightning strikes are there each second globally?
100

How high is a typical cloud?
2,000m
(6,550ft)

How many thunderstorms break out worldwide at any given moment?
2,000

How hot is the Sun? The core is around
15,000,000°C
(27,000,000°F)

We answer your burning questions about the incredible variety and awesome power of the planet's most intriguing climatic phenomena

We like to be able to control everything, but weather – those changes in the Earth's atmosphere that spell out rain, snow, wind, heat, cold and more – is one of those things that is just beyond our power. Maybe that's why a cloudless sunny day or a spectacular display of lightning both have the ability to delight us. Meteorologists have come a long way in their capability to predict weather patterns, track changes and forecast what we can expect to see when we leave our homes each day. But they're not always right. It's not their fault; we still don't completely understand all of the processes that contribute to changes in the weather.

Here's what we do know: all weather starts with contrasts in air temperature and moisture in the atmosphere. Seems simple, right? Not exactly. Temperature and moisture vary greatly depending on a huge number of factors, like the Earth's rotation, where you're located, the angle at which the Sun is hitting it at any given time, your elevation, and your proximity to the ocean. These all lead to changes in atmospheric pressure. The atmosphere is chaotic, meaning that a very small, local change can have a far-reaching effect on much larger weather systems. That's why it's especially tough to make accurate forecasts more than a few days in advance.

DID YOU KNOW? *Many types of animals are reported to have fallen from the sky including frogs, worms and fish*

Is there a way to tell how close a storm is?

Lightning and thunder always go together, because thunder is the sound that results from lightning. Lightning bolts are close to 30,000 degrees Celsius (54,000 degrees Fahrenheit), so the air in the atmosphere that they zip through becomes superheated and quickly expands. That sound of expansion is called thunder, and on average it's about 120 decibels (a chainsaw is 125, for reference). Sometimes you can see lightning but not hear the thunder, but that's only because the lightning is too far away for you to hear it. Because light travels faster than sound, you always see lightning before hearing it.

1. Start the count
When you see a flash of lightning, start counting. A stopwatch would be the most accurate way.

2. Five seconds
The rule is that for every five seconds, the storm is roughly 1.6 kilometres (one mile) away.

3. Do the maths
Stop counting after the thunder and do the maths. If the storm's close, take the necessary precautions.

Lightning occurs most often in hot, summer-like climates

Where are you most likely to get hit by lightning?

Generally lightning strikes occur most often during the summer. So the place where lightning strikes occur the most is a place where summer-like weather prevails year-round: Africa. Specifically, it's the village of Kifuka in the Democratic Republic of Congo. Each year, it gets more than 150 lightning strikes within one square kilometre. Roy Sullivan didn't live in Kifuka but he still managed to get struck by lightning seven separate times while working as a park ranger in the Shenandoah National Park in the USA. The state in which he lived – Virginia – does have a high incidence of lightning strikes per year, but since Sullivan spent his job outdoors in the mountains, his risk was greater due to his exposure.

What is the fastest wind ever recorded, not in a tornado?

407km/h [253mph]

Gusts recorded during Cyclone Olivia in 1996

Is it possible to stop a hurricane?

We can't control the weather… or can we? Some scientists are trying to influence the weather through cloud seeding, or altering the clouds' processes by introducing chemicals like solid carbon dioxide (aka dry ice), calcium chloride and silver iodide. It has been used to induce rainfall during times of drought as well as to prevent storms.

CAN IT REALLY RAIN ANIMALS?

Animals have fallen from the sky before, but it's not actually 'raining' them. More likely strong winds have picked up large numbers of critters from ponds or other concentrations – perhaps from tornadoes or downspouts – then moved and deposited them. Usually the animals in question are small and live in or around water for a reason.

DOES FREAK WEATHER CONFUSE WILDLIFE?

A short period of unseasonable weather isn't confusing for wildlife, but a longer one can be. For example, warm weather in winter may make plants bloom too early or animals begin mating long before spring actually rolls around.

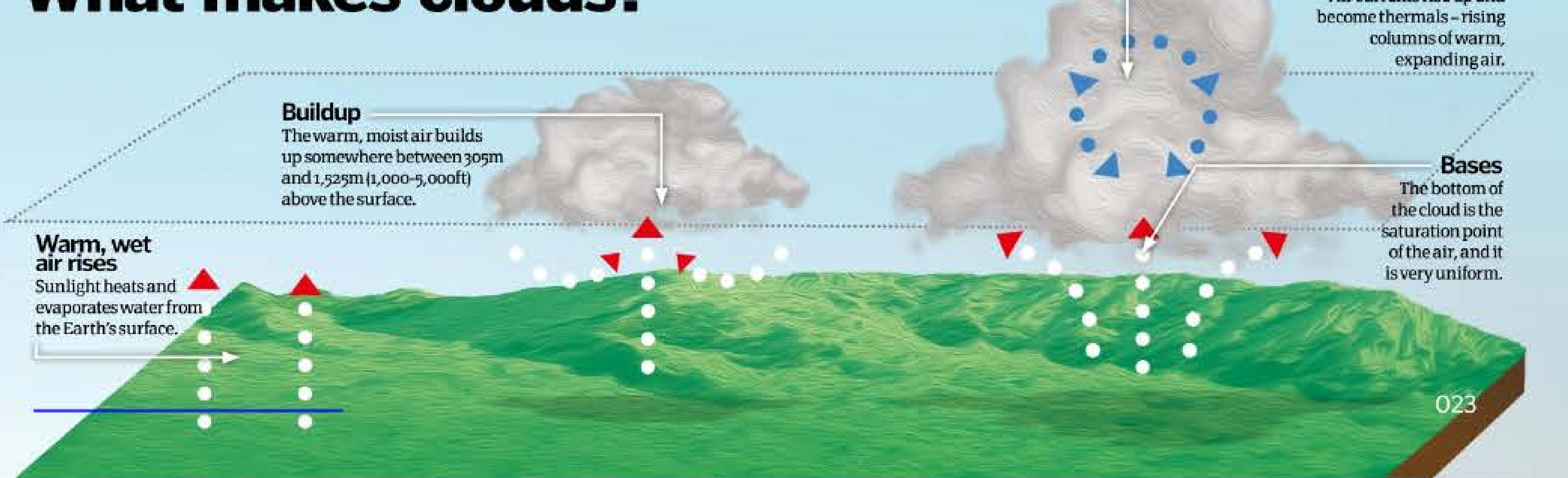
IS THE 'RED SKY AT NIGHT, SHEPHERD'S DELIGHT' SAYING TRUE?

The rest of the proverb is, 'Red sky at morning, shepherd's warning'. A red sky means you could see the red wavelength of sunlight reflecting off clouds. At sunrise, it was supposed to mean the clouds were coming towards you so rain might be on the way. If you saw these clouds at sunset, the risk had already passed. Which is 'good' or 'bad' is a matter of opinion.

WHAT ARE SNOW DOUGHNUTS?

Snow doughnuts, also known as rollers, are a rare natural phenomenon. If snow falls in a clump, gravity can pull it down over itself as it rolls. Normally it would collapse, but sometimes a hole forms. Wind and temperature also play key roles.

What makes clouds?



Cloud
Air currents rise up and become thermals – rising columns of warm, expanding air.

Buildup
The warm, moist air builds up somewhere between 305m and 1,525m (1,000-5,000ft) above the surface.

Bases
The bottom of the cloud is the saturation point of the air, and it is very uniform.

Warm, wet air rises
Sunlight heats and evaporates water from the Earth's surface.

WHAT ARE KATABATIC WINDS?

From the Greek for 'going downhill', a katabatic wind is also known as a drainage wind. It carries dense air down from high elevations, such as mountain tops, down a slope thanks to gravity. This is a common occurrence in places like Antarctica's Polar Plateau, where incredibly cold air on top of the plateau sinks and flows down through the rugged landscape, picking up speed as it goes. The opposite of katabatic winds are called anabatic, which are winds that blow *up* a steep slope.

DOES IT EVER SNOW IN AFRICA?

Several countries in Africa see snow – indeed, there are ski resorts in Morocco and regular snowfall in Tunisia. Algeria and South Africa also experience snowfall on occasion. It once snowed in the Sahara, but it was gone within 30 minutes. There's even snowfall around the equator if you choose to count the snow-topped peaks of mountains in that area.

WHAT COLOUR IS LIGHTNING?

Usually lightning is white, but it can be every colour of the rainbow. There are a lot of factors that go into what shade the lightning will appear, including the amount of water vapour in the atmosphere, whether it's raining and the amount of pollution in the air. A high concentration of ozone, for example, can make lightning look blue.

WHY DO SOME CITIES HAVE THEIR OWN MICROCLIMATE?

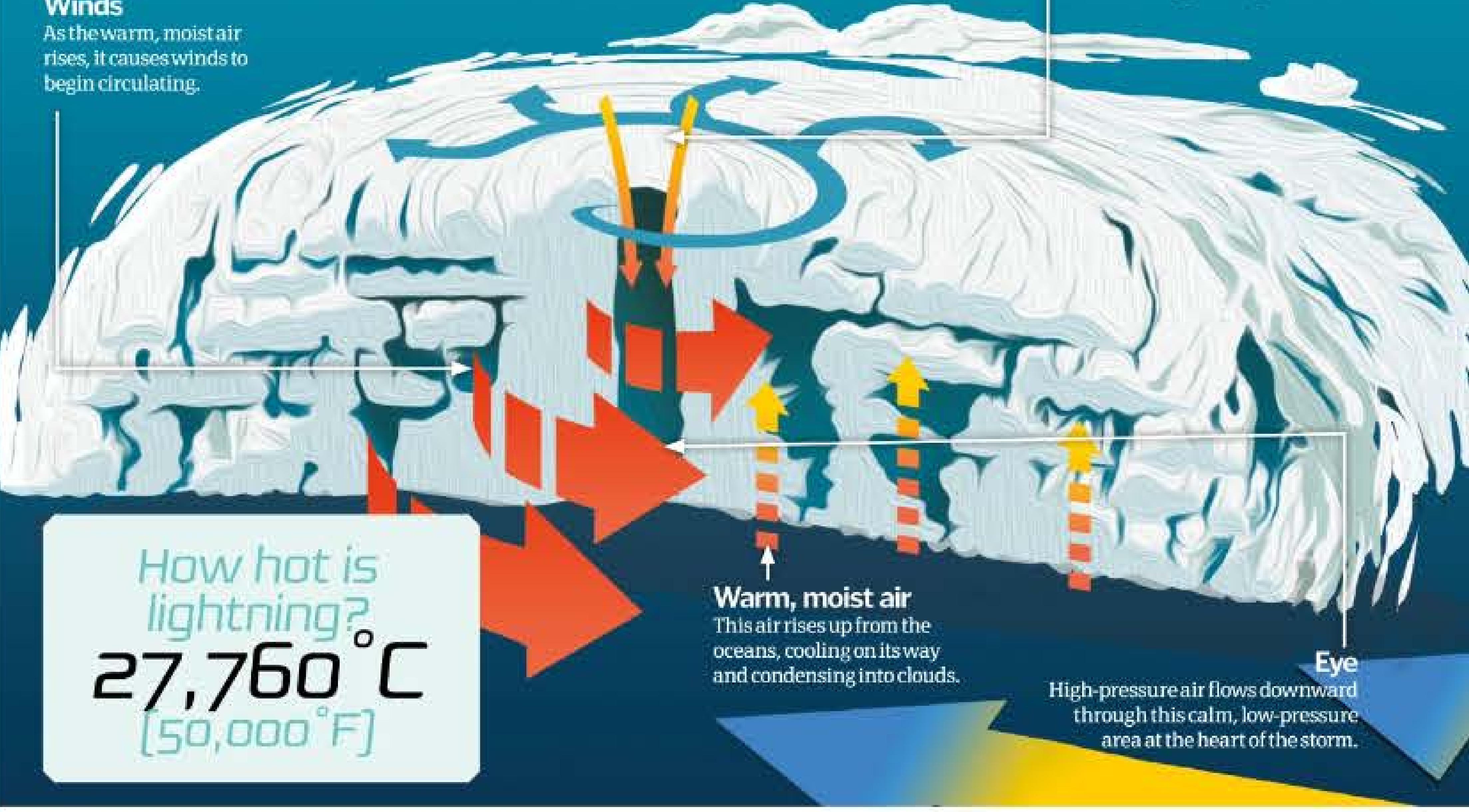
Some large metropolises have microclimates – that is, their own small climates that differ from the local environment. Often these are due to the massive amounts of concrete, asphalt and steel; these materials retain and reflect heat and do not absorb water, which keeps a city warmer at night. This phenomenon specifically is often known as an urban heat island. The extreme energy usage and pollution in large cities may also contribute to this.

What causes hurricanes?

Depending on where they start, hurricanes may also be known as tropical cyclones or typhoons. They always form over oceans around the equator, fuelled by the warm, moist air. As that air rises and forms clouds, more warm, moist air moves into the area of lower pressure below. As the cycle continues, winds begin rotating and pick up speed. Once it hits 119 kilometres (74 miles) per hour, the storm is officially a hurricane. When hurricanes reach land, they weaken and die without the warm ocean air. Unfortunately they can move far inland, bringing a vast amount of rain and destructive winds. People sometimes cite 'the butterfly effect' in relation to hurricanes. This simply means something as small as the beat of a butterfly's wing can cause big changes in the long term.

What are the odds of getting hit by lightning in a lifetime?

1 in 300,000



Winds
As the warm, moist air rises, it causes winds to begin circulating.

Cool, dry air
Cooled, dry air at the top of the system is sucked down in the centre, strengthening the winds.

Warm, moist air
This air rises up from the oceans, cooling on its way and condensing into clouds.

Eye
High-pressure air flows downward through this calm, low-pressure area at the heart of the storm.

How hot is lightning?

27,760°C

[50,000°F]

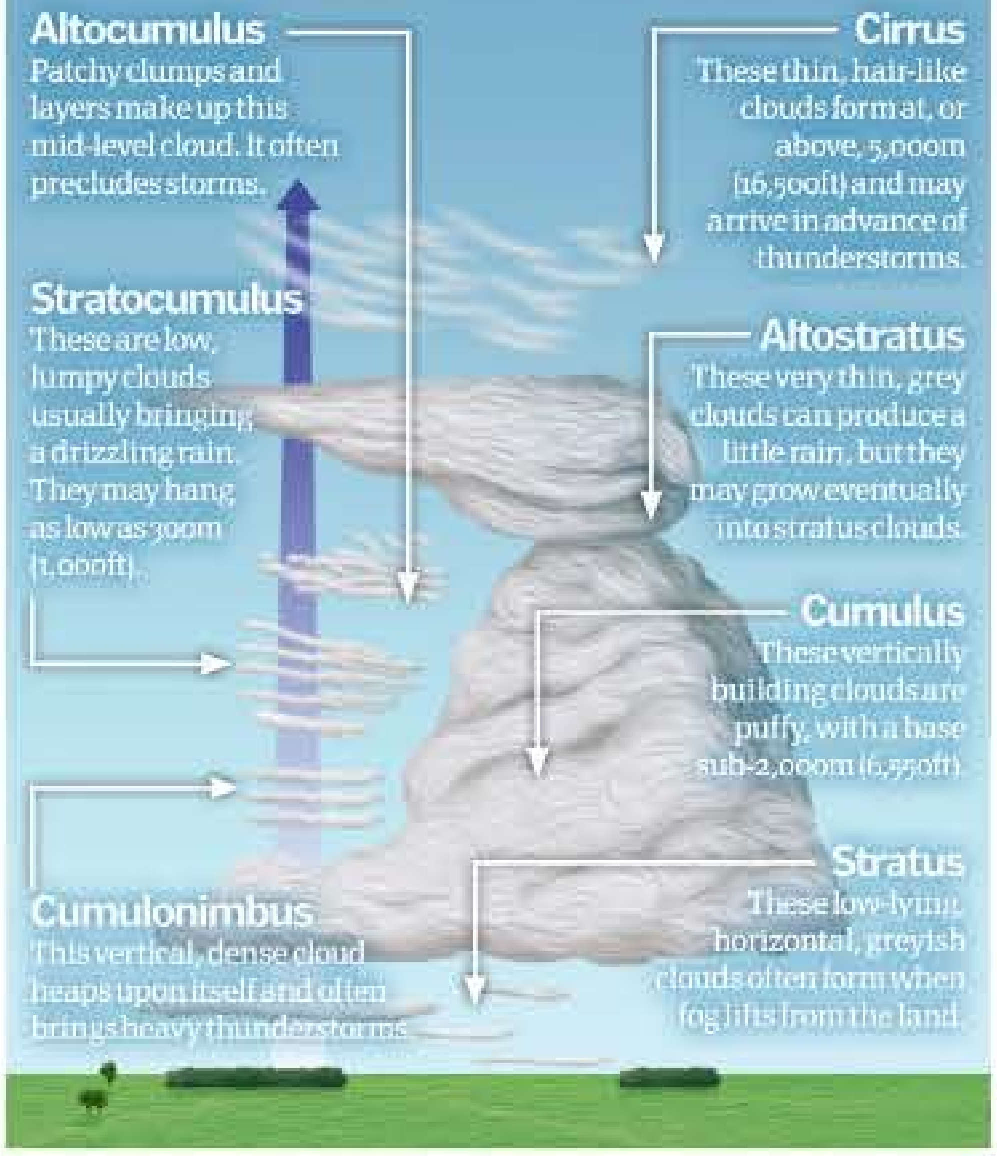
If the Moon didn't exist it would have a catastrophic effect on world climates

© SPL

What would happen to our weather without the Moon?

It's difficult to know exactly what would happen to our weather if the Moon were destroyed, but it wouldn't be good. The Moon powers Earth's tides, which in turn influence our weather systems. In addition, the loss of the Moon would affect the Earth's rotation – how it spins on its axis. The presence of the Moon creates a sort of drag, so its loss would probably speed up the rotation, changing the length of day and night. In addition it would alter the tilt of the Earth too, which causes the changes in our seasons. Some places would be much colder while others would become much hotter. Let's not neglect the impact of the actual destruction, either; that much debris would block out the Sun and rain down on Earth, causing massive loss of life. Huge chunks that hit the ocean could cause great tidal waves, for instance.

Why do clouds look different depending on their height?



Altocumulus
Patchy clumps and layers make up this mid-level cloud. It often precludes storms.

Stratocumulus
These are low, lumpy clouds usually bringing a drizzling rain. They may hang as low as 300m (1,000ft).

Cumulonimbus
This vertical, dense cloud heaps upon itself and often brings heavy thunderstorms.

Cirrus
These thin, hair-like clouds form at, or above, 5,000m (16,500ft) and may arrive in advance of thunderstorms.

Altostratus
These very thin, grey clouds can produce a little rain, but they may grow eventually into stratus clouds.

Cumulus
These vertically building clouds are puffy, with a base sub-2,000m (6,550ft).

Stratus
These low-lying, horizontal, greyish clouds often form when fog lifts from the land.

DID YOU KNOW? *Sir Francis Beaufort devised his wind scale by using the flags and sails of his ship as measuring devices*

How many volts are in a lightning flash?

1 billion

Why are you safer inside a car during an electrical storm?

People used to think the rubber tyres on a car grounded any lightning that may strike it and that's what kept you safe. However, you're safer in your car during an electrical storm because of the metal frame. It serves as a conductor of electricity, and channels the lightning away into the ground without impacting anything – or anyone – inside; this is known as a Faraday cage. While it is potentially dangerous to use a corded phone or other appliances during a storm because lightning can travel along cables, mobile or cordless phones are fine. It's also best to avoid metallic objects, including golf clubs.

© SPL

What is ball lightning?

This mysterious phenomenon looks like a glowing ball of lightning, and floats near the ground before disappearing, often leaving a sulphur smell. Despite many sightings, we're still not sure what causes it.

© SPL

What causes giant hailstones?

Put simply, giant hailstones come from giant storms – specifically a thunderstorm called a supercell. It has a strong updraft that forces wind upwards into the clouds, which keeps ice particles suspended for a long period. Within the storm are areas called growth regions; raindrops spending a long time in these are able to grow into much bigger hailstones than normal.

WHAT IS CLOUD IRIDESCENCE?

This happens when small droplets of water or ice crystals in clouds scatter light, appearing as a rainbow of colours. It's not a common phenomenon because the cloud has to be very thin, and even then the colours are often overshadowed by the Sun.

WHAT DO WEATHER SATELLITES DO?

The GOES (Geostationary Operational Environmental Satellite) system is run by the US National Environmental Satellite, Data, and Information Service (NESDIS). The major element of GOES comprises four different geosynchronous satellites (although there are also other geo-satellites either with other uses now or that have been decommissioned).

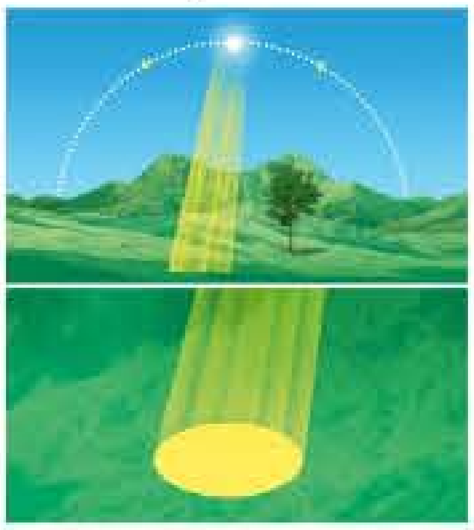
The whole system is used by NOAA's National Weather Service for forecasting, meteorological research and storm tracking. The satellites provide continuous views of Earth, giving data on air moisture, temperature and cloud cover. They also monitor solar and near-space activities like solar flares and geomagnetic storms.

How does the Sun cause the seasons?

Seasons are caused by the Earth's revolution around the Sun, as well as the tilt of the Earth on its axis. The hemisphere receiving the most direct sunlight experiences spring and summer, while the other experiences autumn and winter. During the warmer months, the Sun is higher in the sky, stays above the horizon for longer, and its rays are more direct. During the cooler half, the Sun's rays aren't as strong and it's lower in the sky. The tilt causes these dramatic differences, so while those in the northern hemisphere are wrapping up for snow, those in the southern hemisphere may be sunbathing on the beach.

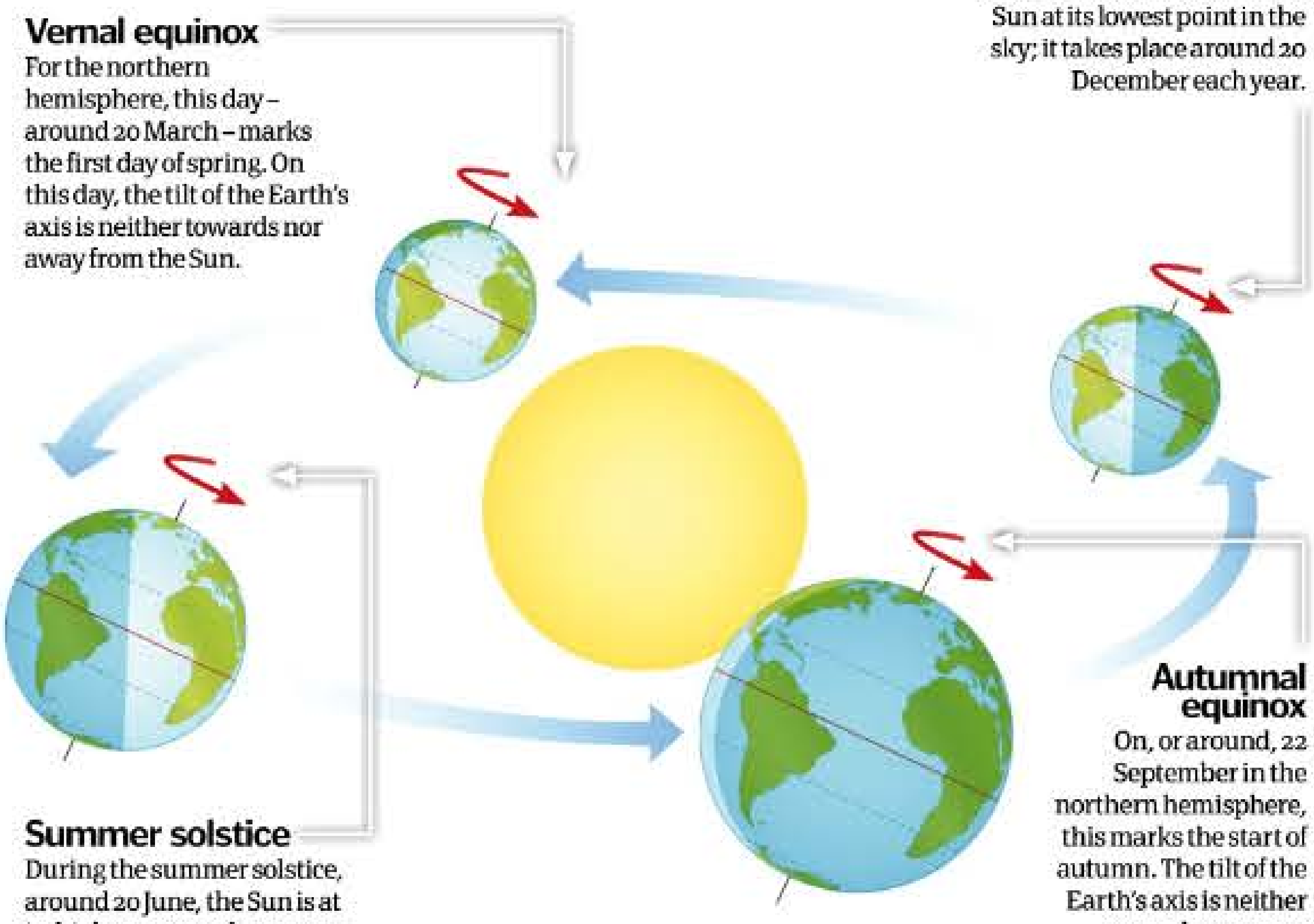
SUMMER

The Sun is at its highest point in the sky and takes up more of the horizon. Its rays are more direct.



WINTER

The Sun is at its lowest point in the sky and there is less daylight. The rays are also more diffuse.



Vernal equinox

For the northern hemisphere, this day – around 20 March – marks the first day of spring. On this day, the tilt of the Earth's axis is neither towards nor away from the Sun.

Winter solstice

The winter solstice marks the beginning of winter, with the Sun at its lowest point in the sky; it takes place around 20 December each year.

Summer solstice

During the summer solstice, around 20 June, the Sun is at its highest, or northernmost, point in the sky.

Autumnal equinox

On, or around, 22 September in the northern hemisphere, this marks the start of autumn. The tilt of the Earth's axis is neither towards nor away from the Sun.

HOW LONG DOES A RAINBOW LAST?

There is no set rule for the duration a rainbow will last. It all depends on how long the light is refracted by water droplets in the air (eg rain, or the spray from a waterfall).

WHY DOES THE AIR SMELL FUNNY AFTER RAIN HAS FALLEN?

This scent comes from bacteria in the soil. Once the earth dries, the bacteria (called actinomycetes) release spores. Rainfall kicks these spores up into the air, and then the moist air disperses them. They tend to have a sweet, earthy odour.

HOW MUCH RAIN CAN A HURRICANE BRING?

The average hurricane, with a radius of about 1,330 kilometres (825 miles), can dump as much as 21.3 x 10^{19} cubic centimetres (1.3 x 10^{19} cubic inches) of water in one day. That's enough rain to fill up 22 million Olympic-size swimming pools!

WHAT ARE DROUGHTS AND HEAT WAVES?

Droughts are about an extreme lack of water, usually due to lower than average rainfall, and last for months or even years. There's no set definition of a heat wave, but it typically means higher than average temperatures for several consecutive days. Both can lead to crop failures and fatalities.

WHY ARE RAINBOWS ARCH-SHAPED?

Rainbows are arched due to the way sunlight hits raindrops. It bends as it passes through because it slows during this process. Then, as the light passes out of the drop, it bends again as it returns to its normal speed.

How hot was the hottest day in history?

58°C (136°F)

Recorded on 13 September 1922 in Al Aziziyah, Libya

What's the difference between rain, sleet and snow?

When it comes to precipitation, it's all about temperature. When the air is sufficiently saturated, water vapour begins to form clouds around ice, salt or other cloud seeds. If saturation continues, water droplets grow and merge until they become heavy enough to fall as rain. Snow forms when the air is cold enough to freeze supercooled water droplets – lower than -31 degrees Celsius (-34 degrees Fahrenheit) – then falls. Sleet is somewhere in between: it starts as snow but passes through a layer of warmer air before hitting the ground, resulting in some snow melting.

What are gravity wave clouds?

Gravity waves are waves of air moving through a stable area of the atmosphere. The air might be displaced by an updraft or something like mountains as the air passes over. The upward thrust of air creates bands of clouds with empty space between them. Cool air wants to sink, but if it is buoyed again by the updraft, it will create additional gravity wave clouds.

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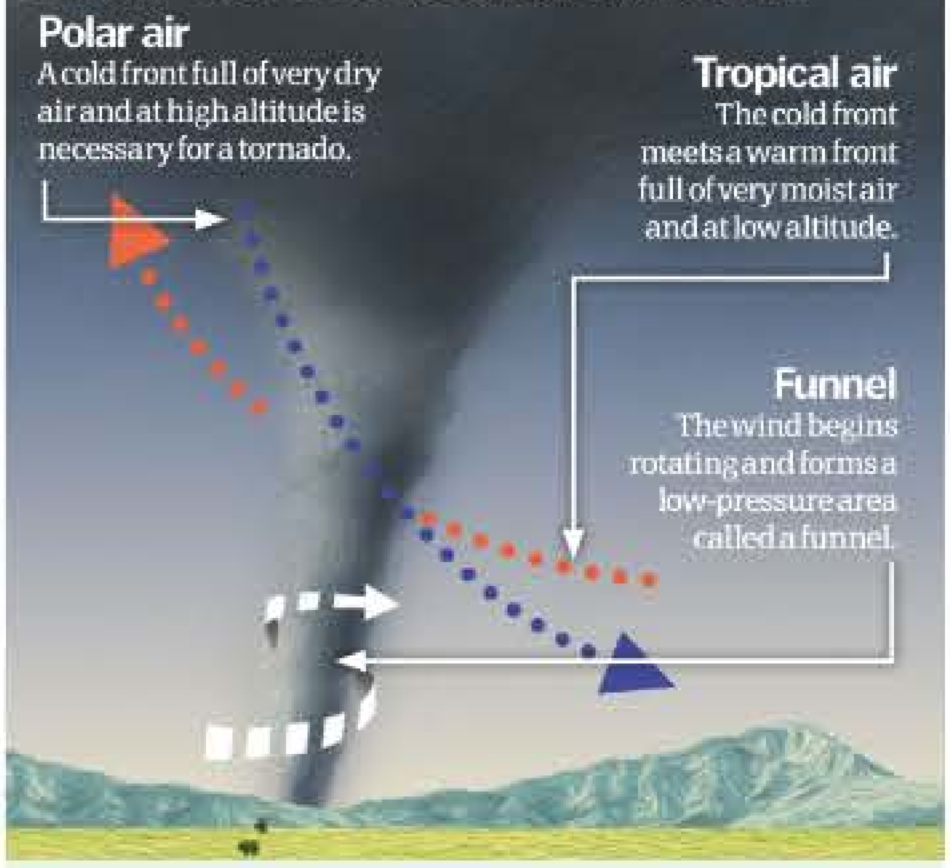
How do tornadoes work?



Polar air
A cold front full of very dry air and at high altitude is necessary for a tornado.

Tropical air
The cold front meets a warm front full of very moist air and at low altitude.

Funnel
The wind begins rotating and forms a low-pressure area called a funnel.

Tornadoes start out with severe thunderstorms called supercells. They form when polar air comes in contact with tropical air in a very unstable atmosphere. Supercells contain a rotating updraft of air that is known as a mesocyclone, which keeps them going for a long time. High winds add to the rotation, which keeps getting faster and faster until eventually it forms a funnel. The funnel cloud creates a sucking area of low pressure at the bottom. As soon as this funnel comes in to contact with the Earth, you have a tornado.

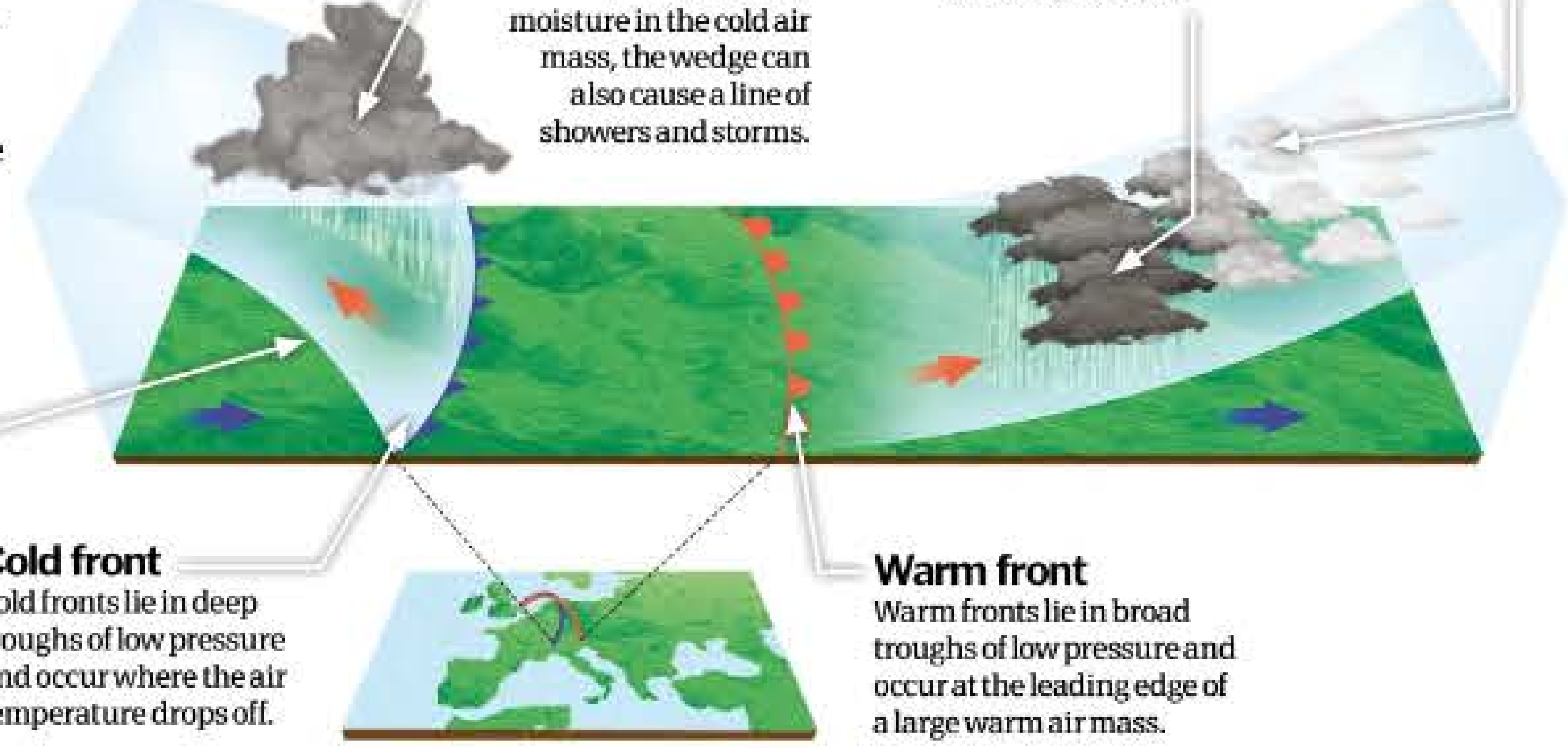
Why is it so quiet after it snows?

It's peaceful after snowfall as the snow has a dampening effect; pockets of air between the flakes absorb noise. However, if it's compacted snow and windy, the snow might actually reflect sound.

What is a weather front?

A weather front is the separation between two different masses of air, which have differing densities, temperature and humidity.

On weather maps, they're delineated by lines and symbols. The meeting of different frontal systems causes the vast majority of weather phenomena.



Wet 'n' wild
If there's a lot of moisture in the cold air mass, the wedge can also cause a line of showers and storms.

Thunderstorms
Unstable masses of warm air often contain stratiform clouds, full of thunderstorms.

Fog
Fog often comes before the slow-moving warm front.

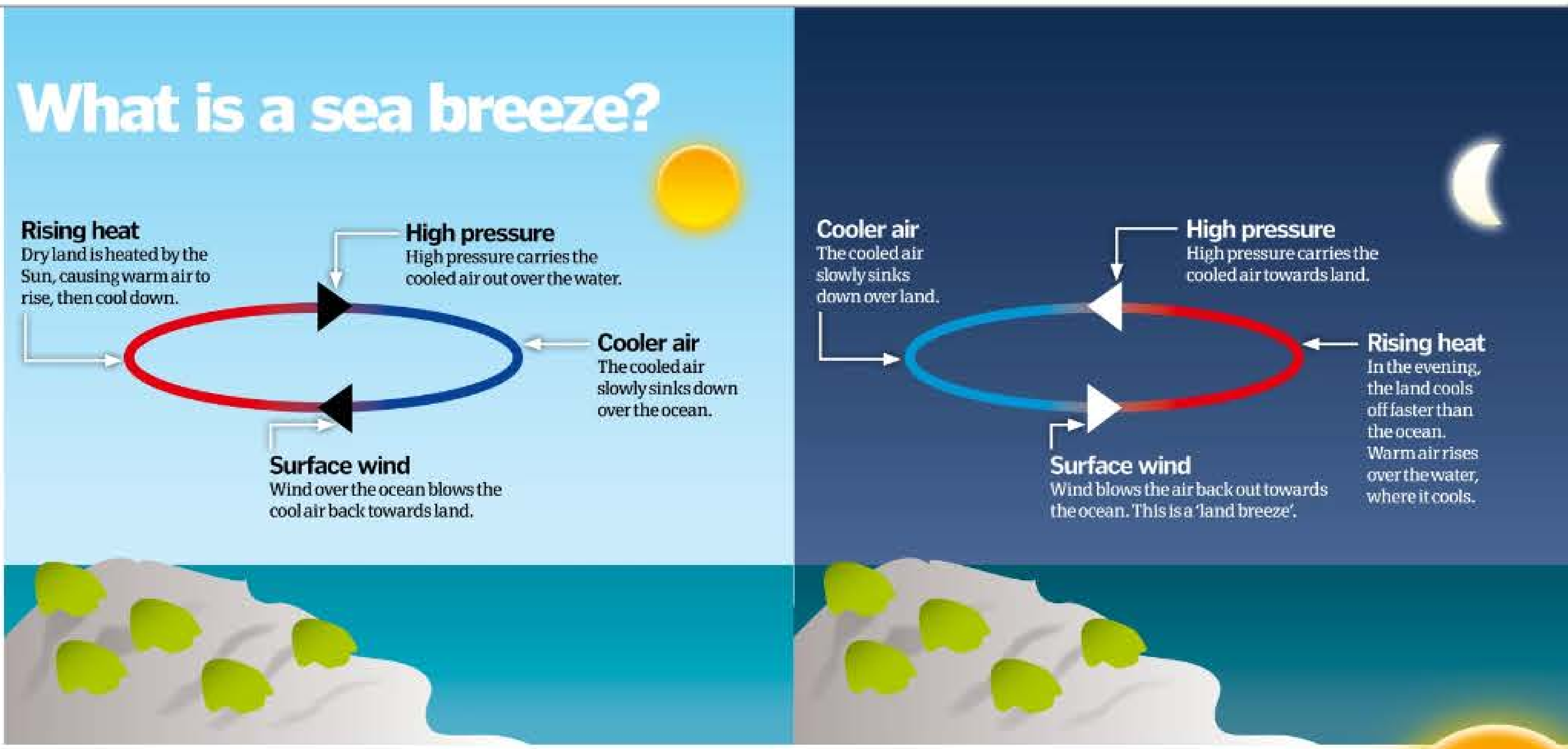
Wedge
As cold air is denser, it often 'wedges' beneath the warm air. This lift can cause wind gusts.

Cold front
Cold fronts lie in deep troughs of low pressure and occur where the air temperature drops off.

Warm front
Warm fronts lie in broad troughs of low pressure and occur at the leading edge of a large warm air mass.

DID YOU KNOW? *Fog is made up of millions of droplets of water floating in the air*

What is a sea breeze?


Rising heat
Dry land is heated by the Sun, causing warm air to rise, then cool down.
High pressure
High pressure carries the cooled air out over the water.
Cooler air
The cooled air slowly sinks down over the ocean.
Surface wind
Wind over the ocean blows the cool air back towards land.
Cooler air
The cooled air slowly sinks down over land.
High pressure
High pressure carries the cooled air towards land.
Rising heat
In the evening, the land cools off faster than the ocean. Warm air rises over the water, where it cools.
Surface wind
Wind blows the air back out towards the ocean. This is a 'land breeze'.

What is the eye of a storm?

The eye is the calm centre of a storm like a hurricane or tornado, without any weather phenomena. Because these systems consist of circular, rotating winds, air is funnelled downward through the eye and feeds back into the storm itself.

The eye at the centre of a hurricane tends to be 20-50km (12-31mi) in diameter

© NASA

What are red sprites and blue jets?

© SPL

These are both atmospheric and electrical phenomena that take place in the upper atmosphere, and are also known as upper-atmosphere discharge. They take place above normal lightning; blue jets occur around 40-50 kilometres (25-30 miles) above the Earth, while red sprites are higher at 50-100 kilometres (32-64 miles). Blue jets happen in cone shapes above thunderstorm clouds, and are not related to lightning. They're blue due to ionised emissions from nitrogen. Red sprites can appear as different shapes and have hanging tendrils. They occur when positive lightning goes from the cloud to the ground.

Does lightning ever strike in the same place twice?

Yes, lightning often strikes twice in the same location. If there's a thunderstorm and lightning strikes, it's just as likely to happen again. Many tall structures get struck repeatedly during thunderstorms, such as New York City's famed Empire State Building or NASA's shuttle launch pad in Cape Canaveral, Florida.

How cold was the coldest day in recorded history?

-89°C (-129°F)

Recorded on 21 July 1983 at Vostok II Station, Antarctica

Why does the Sun shine?

The Sun is a super-dense ball of gas, where hydrogen is continually burned into helium (nuclear fusion). This generates a huge deal of energy, and the core reaches 15 million degrees Celsius (27 million degrees Fahrenheit). This extreme heat produces lots of light.

WHY ARE CLOUDS FLUFFY?

Fluffy-looking clouds – the big cotton-ball ones – are a type called cumulus. They form when warm air rises from the ground, meets a layer of cool air and moisture condenses. If the cloud grows enough to meet an upper layer of freezing air, rain or snow may fall from the cloud.

WHAT'S IN ACID RAIN?

Acid rain is full of chemicals like nitrogen oxide, carbon dioxide and sulphur dioxide, which react with water in the rain. Much of it comes from coal powerplants, cars and factories. It can harm wildlife and also damage buildings.

WHY CAN I SEE MY BREATH IF IT'S COLD?

Your breath is full of warm water vapour because your lungs are moist. When it's cold outside and you breathe out, that warm vapour cools rapidly as it hits the cold air. The water molecules slow down, begin to change form, and bunch up together, becoming visible.

WHAT IS THE GREEN FLASH YOU SEE AS THE SUN SETS SOMETIMES?

At sunsets (or indeed sunrises), the Sun can occasionally change colour due to refraction. This can cause a phenomenon called green flash. It only lasts for a second or two so can be very tricky to spot.

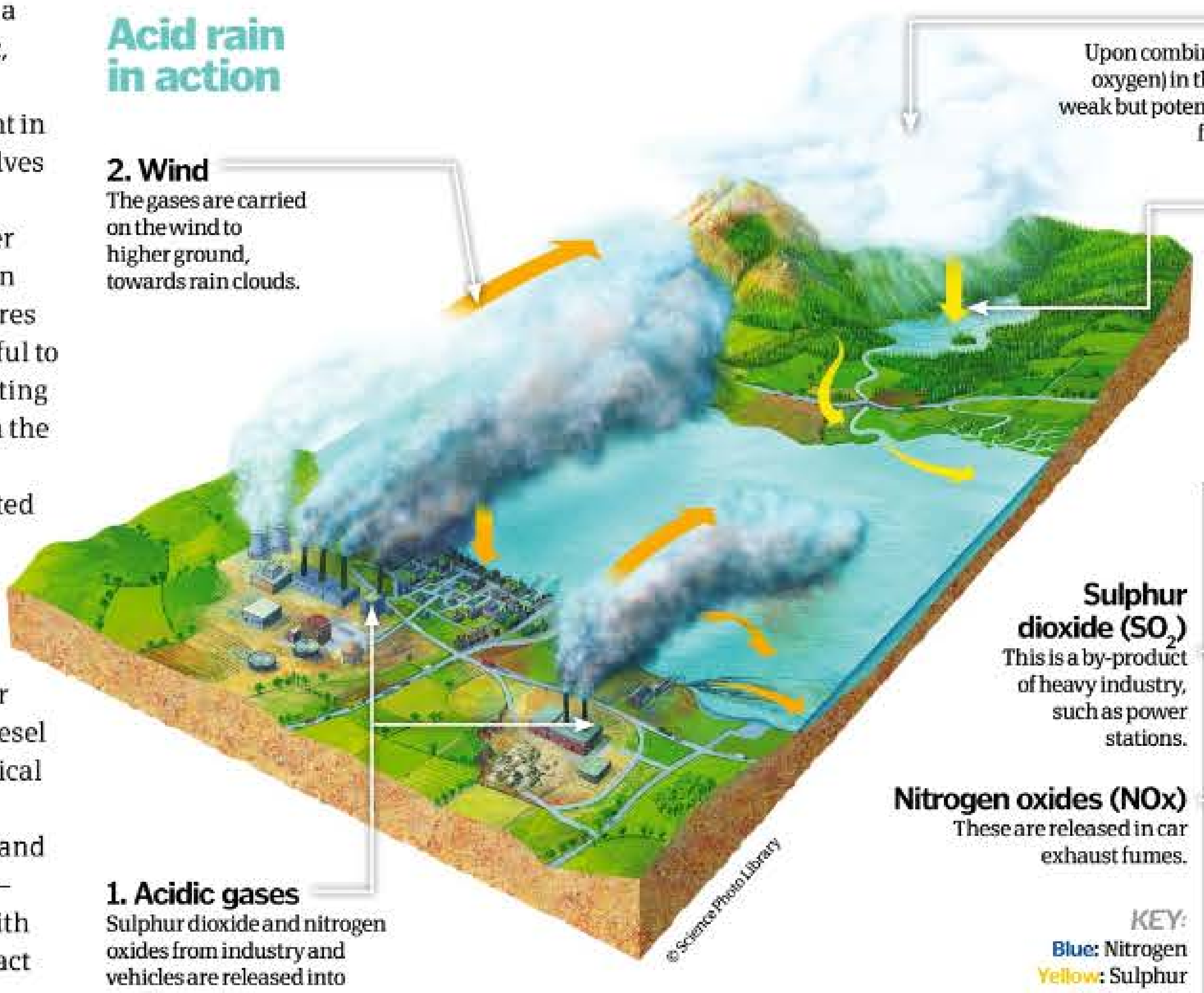
Where does acid rain come from?

We've all seen the effects of acid rain on limestone statues, but how does this damaging substance form?

All rainwater is a little bit acidic, because the carbon dioxide present in the atmosphere dissolves in water and forms carbonic acid. Stronger acid rain, however, can damage stone structures and can also be harmful to crops, as well as polluting waterways. It forms in the atmosphere when poisonous gases emitted by human activities combine with the moisture within rain clouds.

Fossil-fuelled power stations and petrol/diesel vehicles give off chemical pollutants – mainly sulphur dioxide (SO_2) and nitrogen oxides (NOx) – which when mixed with the water in the air react and turn acidic.

Acid rain in action



1. Acidic gases
Sulphur dioxide and nitrogen oxides from industry and vehicles are released into the atmosphere.

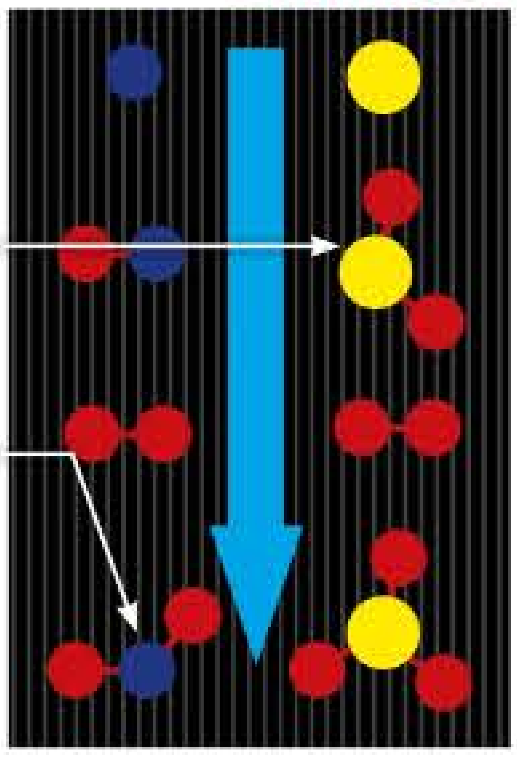
2. Wind
The gases are carried on the wind to higher ground, towards rain clouds.

3. Gasses dissolve
Upon combining with the water vapour (water and oxygen) in the rain clouds, the gasses react to form weak but potentially damaging acid. Sulphur dioxide from industry becomes sulphuric acid.

4. Acid rainfall
When acid rain falls it can damage plant life, infiltrate waterways and erode buildings and statues.

© Science Photo Library

Oxidation of sulphur and nitrogen



Sulphur dioxide (SO_2)
This is a by-product of heavy industry, such as power stations.

Nitrogen oxides (NOx)
These are released in car exhaust fumes.

KEY:
Blue: Nitrogen
Yellow: Sulphur
Red: Oxygen

The smell of rain

Find out why precipitation creates a distinctive aroma that's the same all over the world

It's possible to smell rain before it has even fallen. Lightning has the power to split atmospheric nitrogen and oxygen molecules into individual atoms. These atoms react to form nitric oxide, which in turn can interact with other chemicals to form ozone – the aroma of which is a bit like chlorine and a specific smell we associate with rain. When the scent carries on the wind, we can predict the rain before it falls.

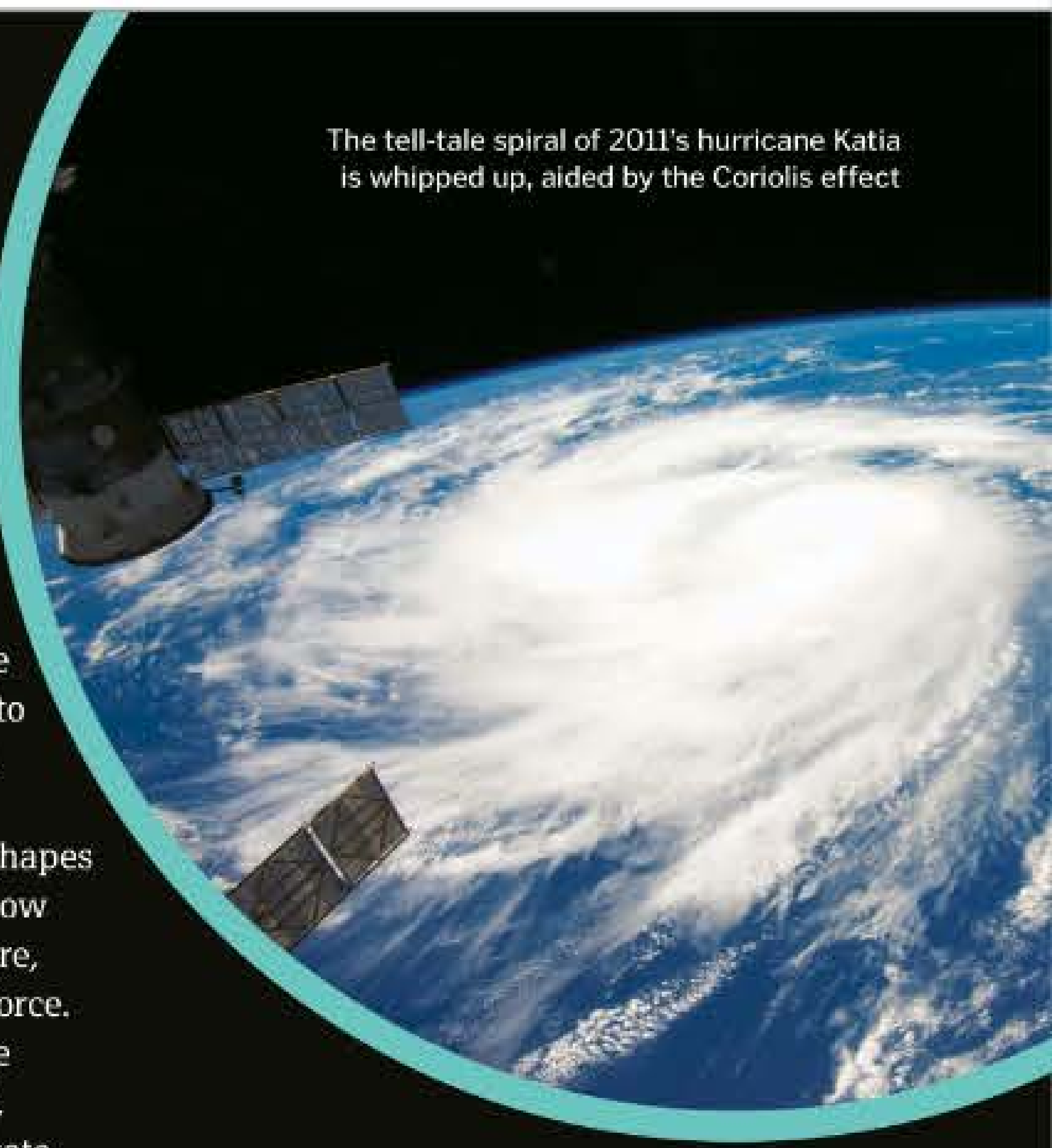
Another smell associated with rain is petrichor – a term coined by a couple of Australian scientists in the mid-Sixties. After a dry spell of weather, the first rain that falls brings with it a very particular aroma that is the same no matter where you are. Two chemicals are responsible for the production of this indescribable odour called petrichor. One of the two chemicals is released by a specific bacteria found in the earth; the other is an oil secreted by thirsty plants. These compounds combine on the ground and, when it rains, the smell of petrichor will fill your nostrils.

© Thinkstock

DID YOU KNOW? *Clouds on Venus are actually composed of sulphur dioxide and drops of sulphuric acid*

Global wind patterns

Wind paths, ocean currents and even airplanes are governed by the same invisible force


The tell-tale spiral of 2011's hurricane Katia is whipped up, aided by the Coriolis effect

Winds in our atmosphere do not travel in straight lines due to a phenomena known as the Coriolis effect. As the Earth spins on its axis, the motion deflects the air above it. The planet's rotation is faster at the equator, because this is where the Earth is widest. This difference in speed causes the deflection – for example, if you were to throw a ball from the equator to the North Pole it would appear to curve off-course.

If Earth didn't spin like this, air on the planet would simply circulate back and forth between the high-pressure poles and the low-pressure equator. When the rotation of the Earth is added into the mix, it causes the air in the Northern Hemisphere to be deflected to the right, and air in the Southern Hemisphere to the left, away from the equator. As a result, winds circulate in cells.

It's this effect that causes the rotational shapes of large storms that form over oceans. The low pressure of cyclones sucks air into the centre, which then deflects thanks to the Coriolis force. This explains why cyclones that form in the Northern Hemisphere spin anti-clockwise, while in the Southern Hemisphere they rotate clockwise. The opposite is also true of high pressure storms, also known as anticyclones, which rotate clockwise in the north and anti-clockwise in the south.

The Coriolis effect is so prevalent that it also governs the movement of long-range airborne objects such as airplanes and missiles. Pilots have to adjust their flight routes to compensate.

Coriolis effect on water

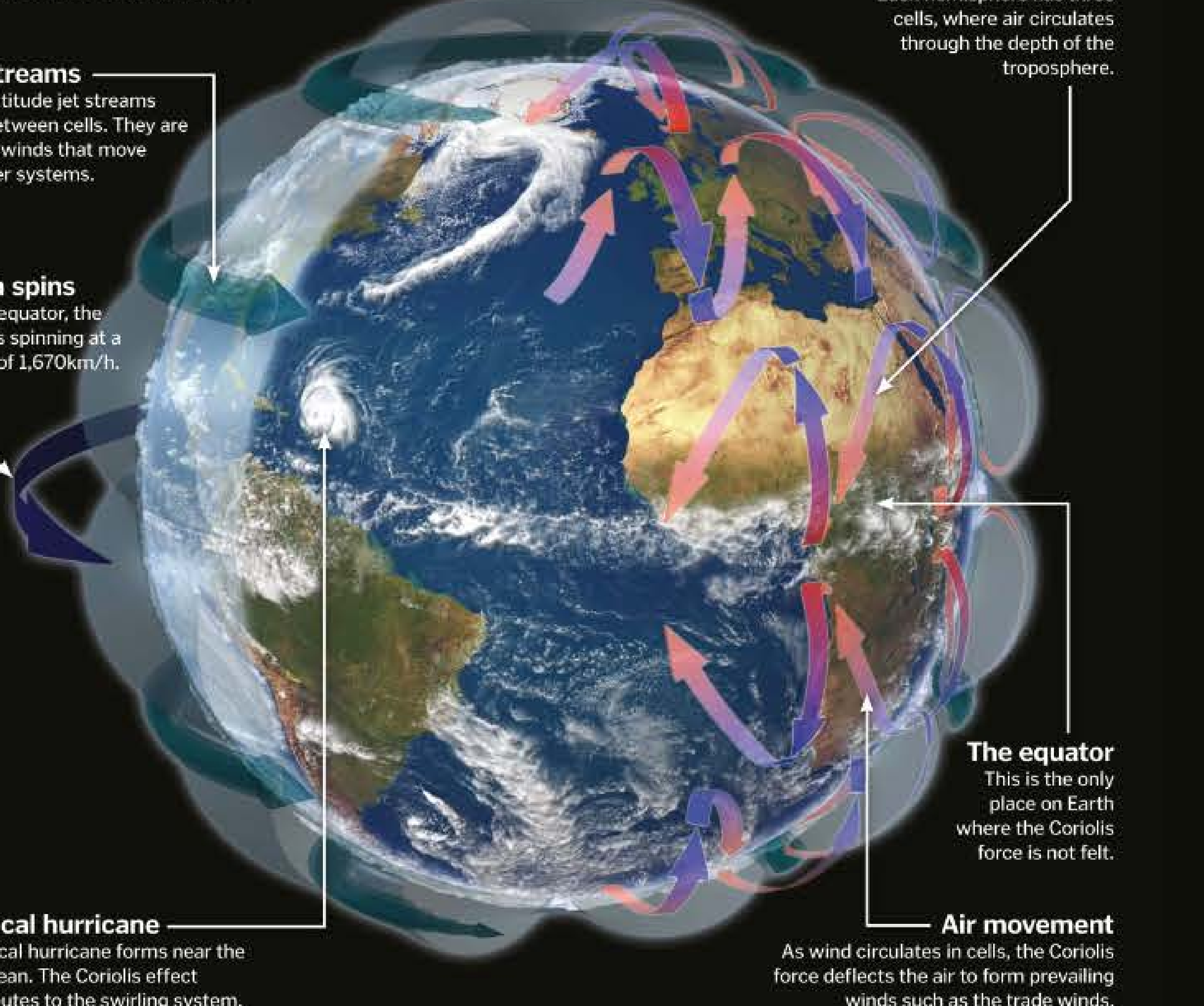
It is commonly believed that the Coriolis effect is the reason why water is perceived to spiral down the drain in one direction in the Northern Hemisphere, and in the opposite direction below the equator. However, the Coriolis effect isn't felt on such a small scale. The Coriolis effect does affect ocean currents, though.

Each ocean basin has a 'gyre' – a strong circulating current that moves around the basin. The deflected winds cause drag on the ocean surface, which translates into deep currents. Gyres in the Northern Hemisphere turn in a clockwise spiral, and they turn anti-clockwise in the Southern Hemisphere. There are no gyres crossing the equator so the Coriolis effect is not felt there.

Local factors such as the positioning of taps has more effect on water drainage direction

Global winds

How Earth's spin affects the winds, their direction and function



Jet streams
High-altitude jet streams flow between cells. They are strong winds that move weather systems.

Earth spins
At the equator, the Earth is spinning at a speed of 1,670km/h.

Tropical hurricane
A tropical hurricane forms near the Caribbean. The Coriolis effect contributes to the swirling system.

Wind cells
Each hemisphere has three cells, where air circulates through the depth of the troposphere.

The equator
This is the only place on Earth where the Coriolis force is not felt.

Air movement
As wind circulates in cells, the Coriolis force deflects the air to form prevailing winds such as the trade winds.

How do jet streams work?

They're a vital component in regulating global weather, but what do jet streams actually do?

Jet streams are currents of fast-moving air found high in the atmosphere of some planets. Here on Earth, when we refer to 'the jet stream', we're typically talking about either of the polar jet streams. There are also weaker, subtropical jet streams higher up in the atmosphere, but their altitude means they have less of an effect on commercial air traffic and the weather systems in more populated areas.

The northern jet stream travels at about 161-322 kilometres (100-200 miles) per hour from west to east, ten kilometres (six miles) above the surface in a region of the atmosphere known as the tropopause (the border between the troposphere and the stratosphere). It's created by a combination of our planet's rotation, atmospheric heating from the Sun and the Earth's own heat from its core creating temperature differences and, thus, pressure gradients along which air rushes.

In the northern hemisphere, the position of the jet stream can affect the weather by bringing in or pushing away the cold air from the poles. Generally, if it moves south, the weather can turn wet and windy; too far south and it will become much colder than usual. The reverse is true if the jet stream moves north, inducing drier and hotter weather than average as warm air moves in from the south.

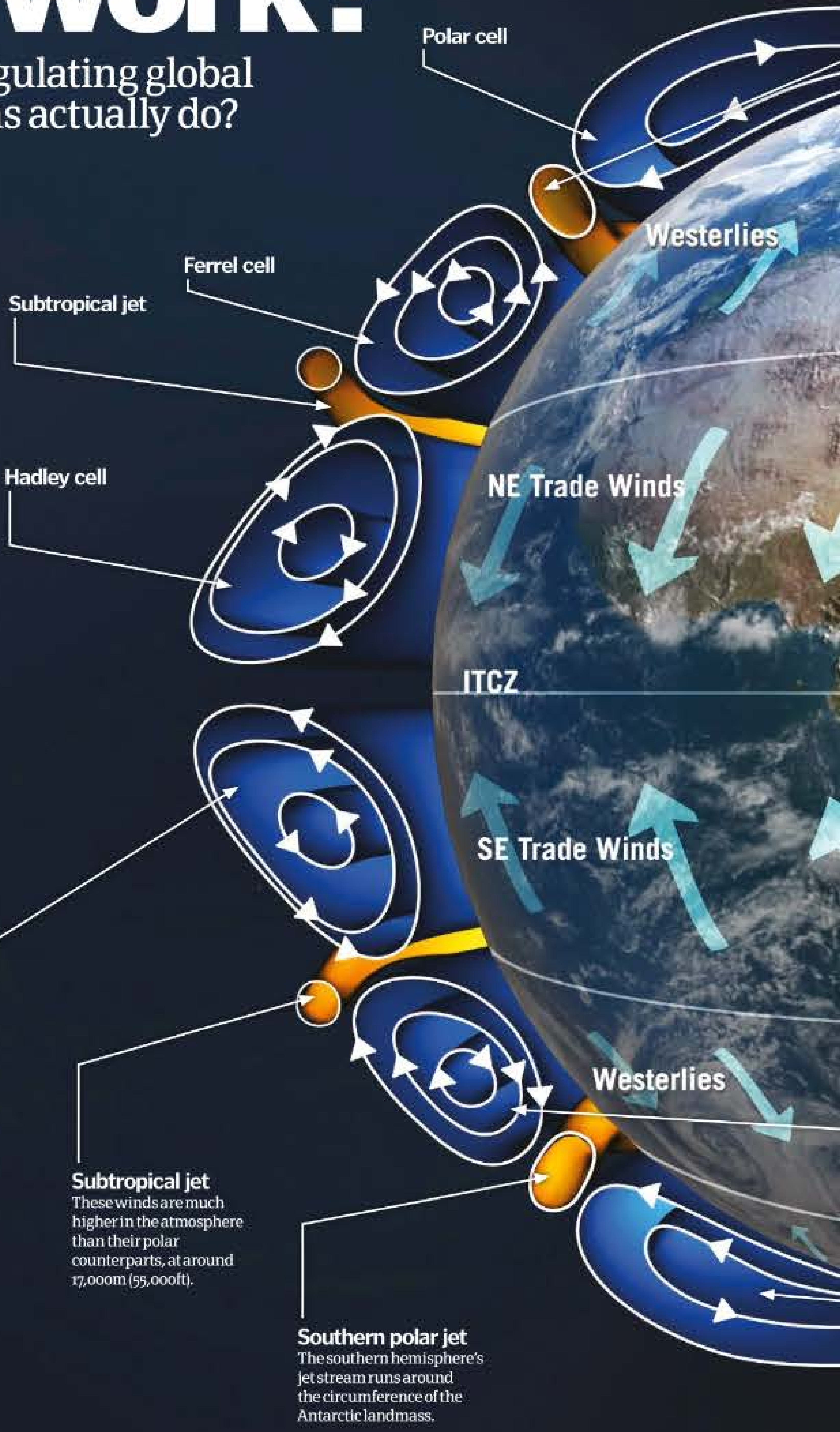
In the southern hemisphere, meanwhile, the jet stream tends to be weakened by a smaller temperature contrast created by the greater expanse of flat, even ocean surface, although it can impact the weather in exactly the same way as the northern jet stream does.

Winds of change

Currents in the jet stream travel at various speeds, but the wind is at its greatest velocity at the centre, where jet streaks can reach speeds as fast as 322 kilometres (200 miles) per hour. Pilots are trained to work with these persistent winds when flying at jet stream altitude, but wind shear is a dangerous phenomenon that they must be ever vigilant of. This is a sudden, violent change in wind direction and speed that can happen in and around the jet stream, affecting even winds at ground level. A sudden gust like this can cause a plane that's taking off/landing to crash, which is why wind shear warning systems are equipped as standard on all commercial airliners.

Earth's jet streams

A closer look at some of the invisible phenomena that play a major role in our planet's climate

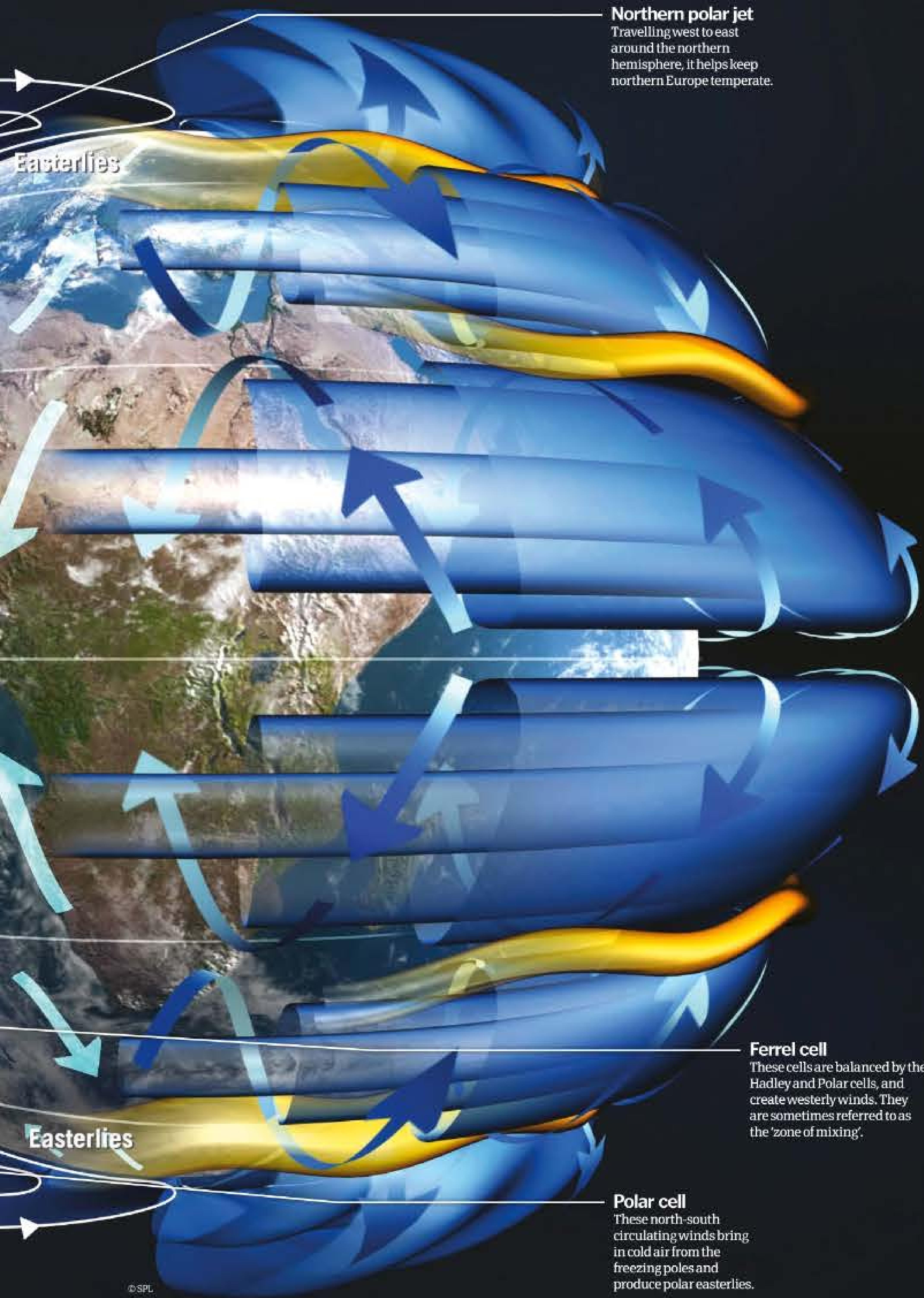


Hadley cell
This atmospheric cell is partly responsible for the deserts and rainstorms in the tropics.

Subtropical jet
These winds are much higher in the atmosphere than their polar counterparts, at around 17,000m (55,000ft).

Southern polar jet
The southern hemisphere's jet stream runs around the circumference of the Antarctic landmass.

DID YOU KNOW? Mount Everest is so high that its 8,848m (29,029ft) summit actually sits in a jet stream



Northern polar jet
Travelling west to east around the northern hemisphere, it helps keep northern Europe temperate.

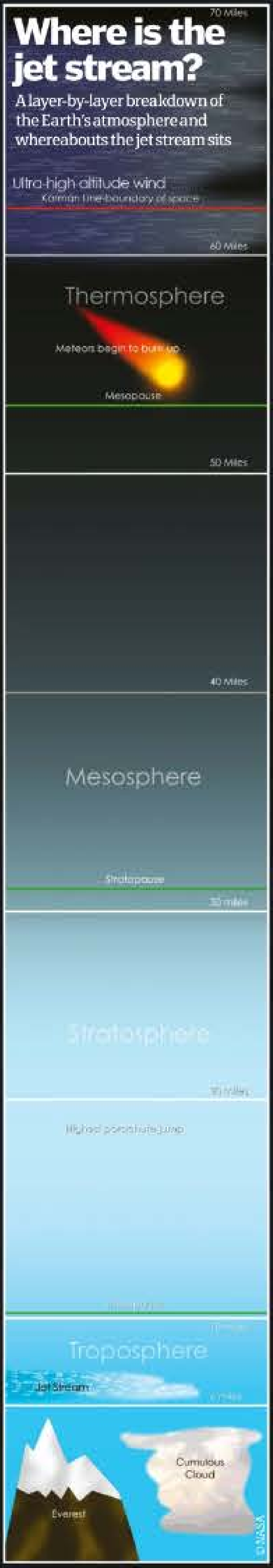
Ferrel cell
These cells are balanced by the Hadley and Polar cells, and create westerly winds. They are sometimes referred to as the 'zone of mixing'.

Polar cell
These north-south circulating winds bring in cold air from the freezing poles and produce polar easterlies.

© SPL

Where is the jet stream?

A layer-by-layer breakdown of the Earth's atmosphere and whereabouts the jet stream sits



© NASA

The sulphur cycle

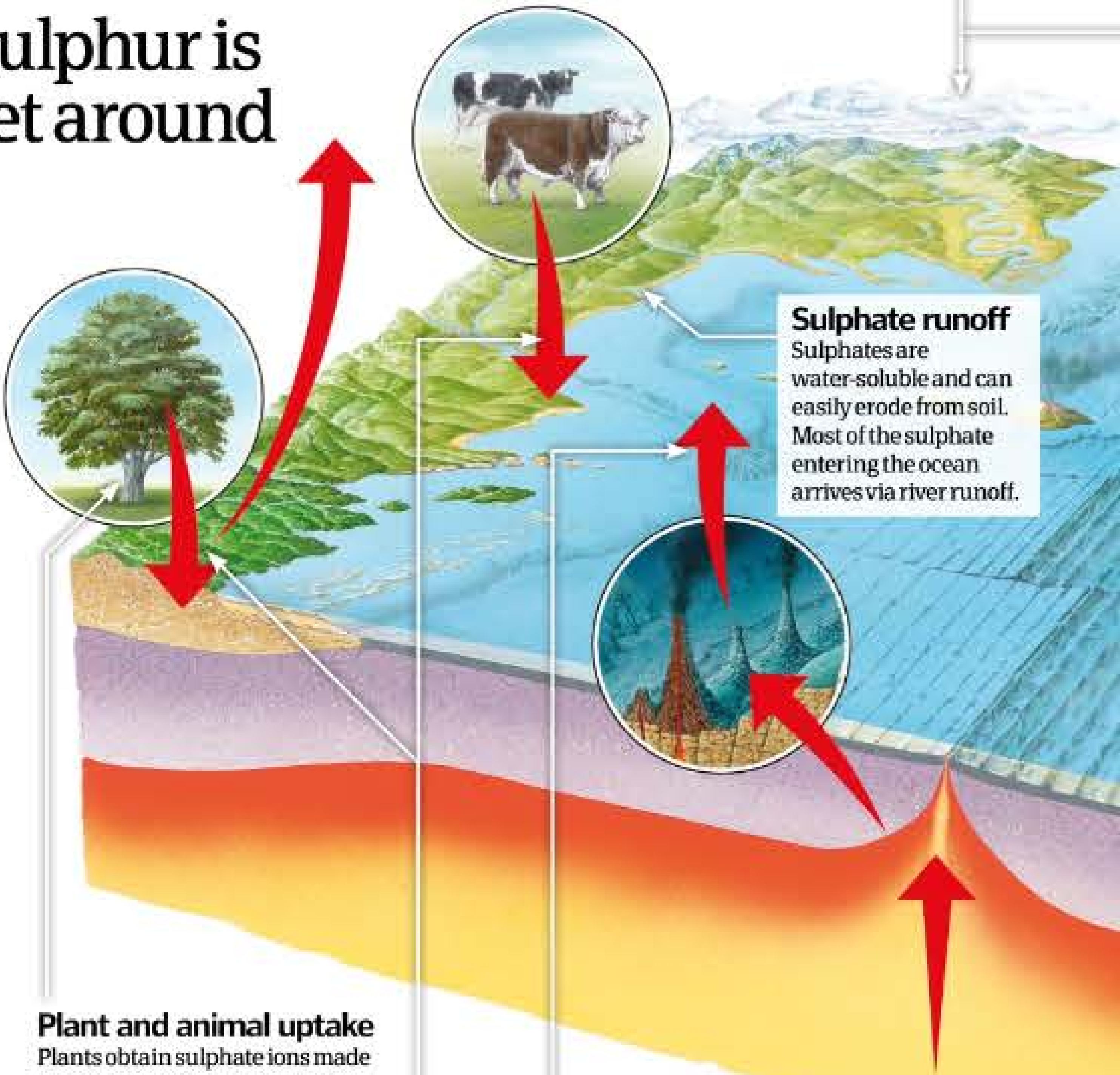
Always mixing and mingling, sulphur is an element that really likes to get around

The sulphur cycle is one of many biochemical processes where a chemical element or compound moves through the biotic and abiotic compartments of the Earth, changing its chemical form along the way. As with both the carbon and nitrogen cycles, sulphur moves between the biosphere, atmosphere, hydrosphere and lithosphere (the rigid outer layer of the Earth). In biology, the water, oxygen, nitrogen, carbon, phosphorus and sulphur cycles are of particular interest because they are integral to the cycle of life.

Sulphur, which is present in the amino acids cysteine and methionine as well as the vitamin thiamine, is a vital part of all organic material. Plants acquire their supply from microorganisms in the soil and water, which convert it into usable organic forms. Animals acquire sulphur by consuming plants and one another. Both plants and animals release sulphur back into the ground and water as they die and are themselves broken down by microorganisms. This part of the cycle can form its own loop in both terrestrial and aquatic environments, as sulphur is consumed by plants and animals and then released again through decomposition.

But this isn't the only iron that sulphur has in the fire. Elemental sulphur is found around volcanoes and geothermal vents, and when volcanoes erupt, massive quantities of sulphur, mostly in the form of sulphur dioxide, can be propelled into the atmosphere. Weathering of rocks and the production of volatile sulphur compounds in the ocean can also both lead to the release of sulphur. Increasingly, atmospheric sulphur is a result of human activity, such as the burning of fossil fuels.

Once in the air, the sulphur dioxide reacts with oxygen and water to form sulphate salts and sulphuric acid. These two compounds dissolve well in water and may return to Earth's surface via both wet and dry deposition. Of course, not all the sulphur is getting busy; there are also vast reservoirs in the planet's crust as well as in oceanic sediments.



Atmospheric sulphur
Once in the atmosphere some sulphur aerosols can remain for years, reflecting the Sun's energy back into space and lowering surface temperatures many miles away. The eruption of Mount Tambora in Indonesia is thought to have caused the 'year without summer' reported in Europe and North America in 1816.

Sulphate runoff
Sulphates are water-soluble and can easily erode from soil. Most of the sulphate entering the ocean arrives via river runoff.

Plant and animal uptake
Plants obtain sulphate ions made available by microorganisms in the soil and incorporate them into proteins. These proteins are then consumed by animals.

Organic deposition
When biological material breaks down, sulphur is released by microbes in the form of hydrogen sulphide and sulphate salts, as well as organic sulphate esters and sulphonates.

Wet and dry deposition
The airborne deposition of sulphur compounds, whether sulphate salts or sulphuric acid, is the dominant cause of acidification in both terrestrial and coastal ecosystems.

Sulphur and the climate

Human activities like burning fossil fuels and processing metals generate around 90 per cent of the sulphur dioxide in the atmosphere. This sulphur reacts with water to produce sulphuric acid and with other emission products to create sulphur salts. These new compounds fall back to Earth, often in the form of acid rain. This type of acid deposition can have catastrophic effects on natural communities, upsetting the chemical balance of waterways, killing fish and plant life. If particularly concentrated, acid rain can even damage buildings and cause chemical weathering.

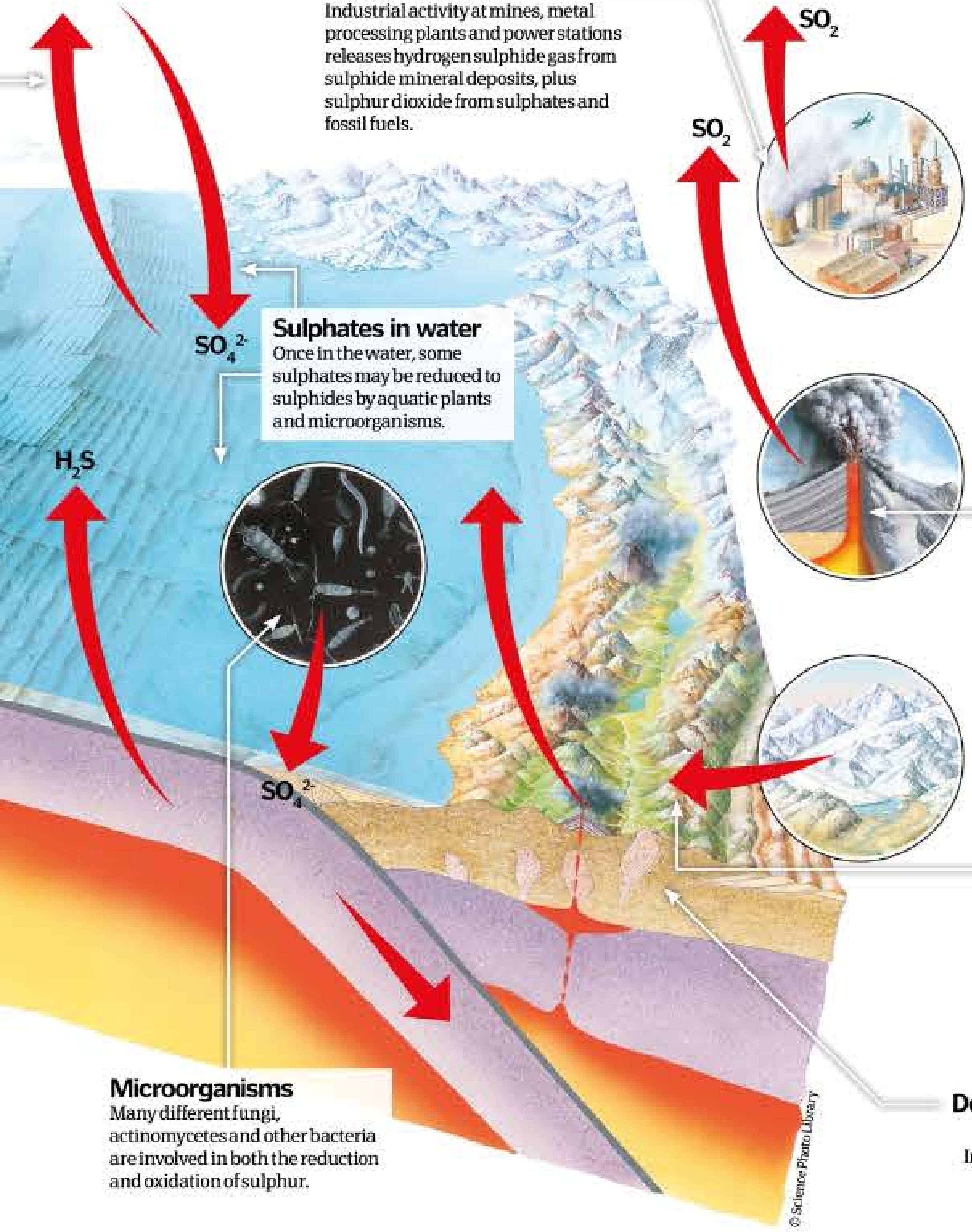
However, the environmental impact of sulphur pollution isn't entirely negative; atmospheric sulphur contributes to cloud formation and absorbs ultraviolet light, somewhat offsetting the temperature increases caused by the greenhouse effect. In addition, when acid rain deposits sulphur in bodies of wetlands, the sulphur-consuming bacteria quickly out-compete methane-producing microbes, greatly reducing the methane emissions which comprise about 22 per cent of the human-induced greenhouse effect.

Burning fossil fuels accounts for a large proportion of the sulphur dioxide in the atmosphere

DID YOU KNOW? *Sulphur is actually the 'brimstone' of biblical fame, where it is said to fuel the fires of hell*

The cycle in action

Sulphur is ubiquitous on Earth but much like your average teenager, the behaviour of sulphur depends heavily on its companions. The element is both necessary for all life and potentially highly toxic, depending on the chemical compound. It moves through different compartments of the planet, taking a range of forms, with many and varied impacts.



Human impact
Industrial activity at mines, metal processing plants and power stations releases hydrogen sulphide gas from sulphide mineral deposits, plus sulphur dioxide from sulphates and fossil fuels.

Sulphates in water
Once in the water, some sulphates may be reduced to sulphides by aquatic plants and microorganisms.

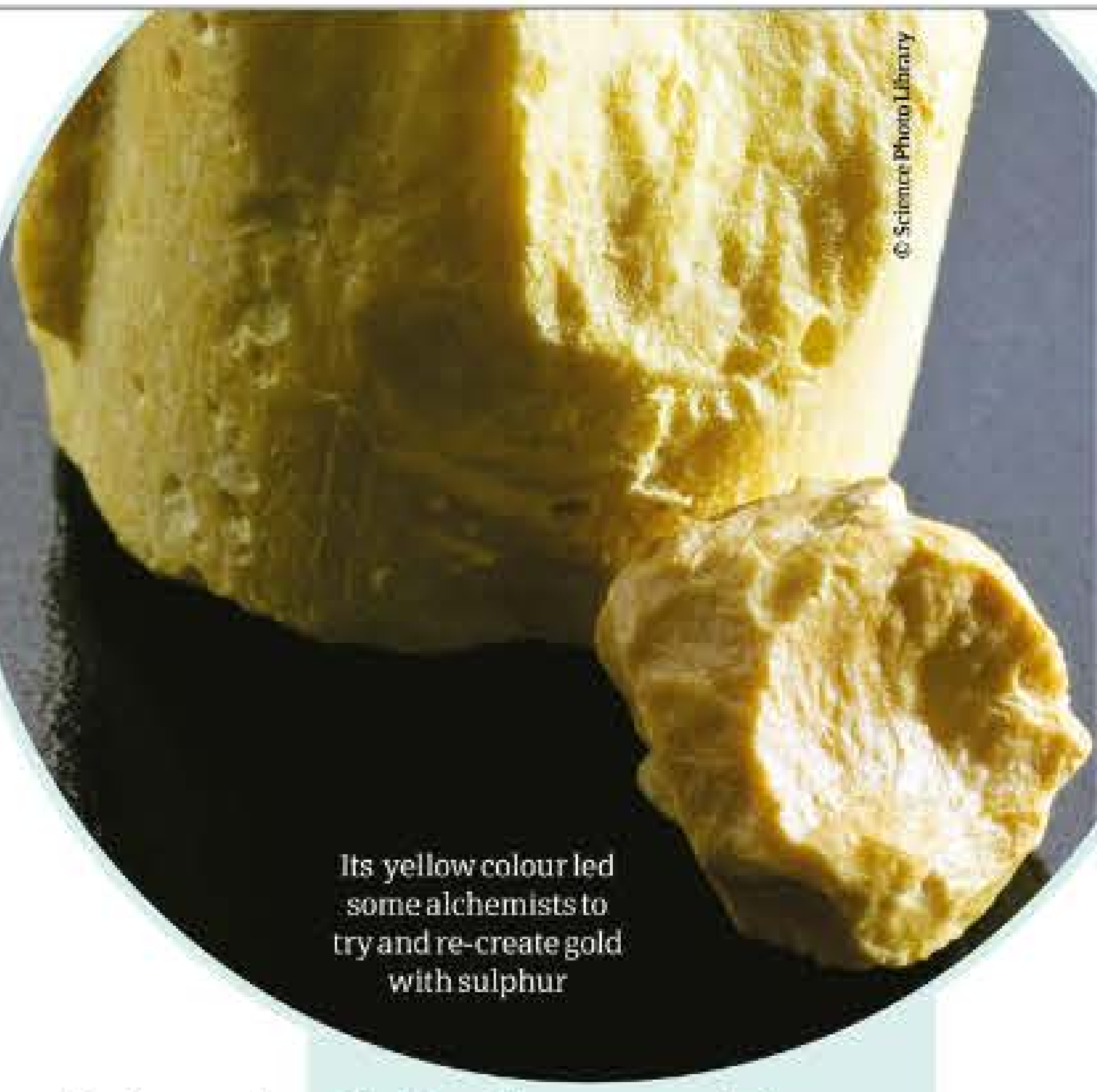
Release of sedimentary sulphur
Volcanic and industrial activity release hydrogen sulphide gas from sulphide mineral deposits, and sulphur dioxide from sulphates and fossil fuels.

Deposition of sulphate minerals
Sulphates are also deposited in sediments as minerals, such as gypsum, a form of calcium sulphate.

Microorganisms
Many different fungi, actinomycetes and other bacteria are involved in both the reduction and oxidation of sulphur.

Deposition of sulphides in sediments
Iron sulphide, known as pyrite, and other sulphide minerals become buried in sediments.

Large quantities of sulphur in its mineral form are found around volcanoes



Its yellow colour led some alchemists to try and re-create gold with sulphur

© Science Photo Library

What is sulphur?

Sulphur is one of the most important and common elements on Earth. It exists in its pure form as a non-metallic solid and is also found in many organic and inorganic compounds. It can be found throughout the Earth's environment, from the soil, air and rocks all the way through to plants and animals.

Because of its bright yellow colour, sulphur was used by early alchemists in their attempts to synthesise gold. That didn't pan out, but people still found many useful applications for it, including making black gunpowder. Today sulphur and sulphur compounds are used in many consumer products such as matches and insecticides. Sulphur is also a common garden additive, bleaching agent and fruit preservative, and is an important industrial chemical in the form of sulphuric acid.

Early users mined elemental sulphur from volcanic deposits, but when the demand for sulphur outstripped supply towards the end of the 19th century, other sources had to be found. Advances in mining techniques enabled the extraction of sulphur from the large salt domes found along the Gulf Coast of the United States. Both volcanic and underground sulphur deposits still contribute to the global supply, but increasingly, industrial sulphur is obtained as a byproduct of natural gas and petroleum refinery processes.

Cave weather

Explore one of China's most stunning cave systems to learn why it has developed its own microclimate

Cut off from the Sun, rain and wind that we experience on the surface, you might assume meteorological conditions in caves never change. However, the reality is that their climates do vary significantly – not only from location to location, but within individual caves over time. Indeed, some examples, like the Er Wang Dong cave system in Chongqing Province, China (main picture), even host their own weather. Ultimately this is because very few caves are 100 per cent cut off from their surroundings.

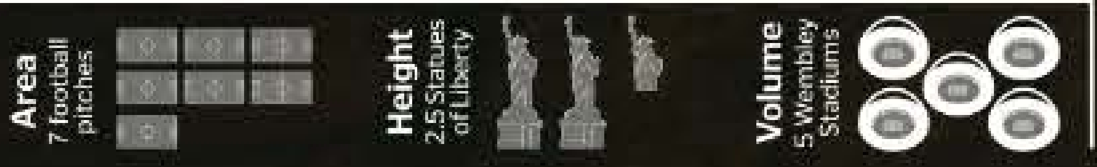
In the case of Er Wang Dong, it all comes down to an imbalance in the local topology. There are several tunnels around the cave system's perimeter where wind can blow in. Once trapped underground air from outside gains moisture, pooling into huge chambers like Cloud Ladder Hall – the second-biggest natural cavern in the world with a volume of 6 million cubic metres (211.9 million cubic feet). Once in an open chamber this humid air rises.

While there are numerous entrances into this subterranean complex, the exits are few and far between. In Cloud Ladder Hall's case, it's a hole in the roof some 250 metres (820 feet) above the floor, leading to a bottleneck effect. As the damp air hits a cooler band near the exit, tiny water droplets condense out to create wispy mist and fog. In the other chambers plants and underground waterways can also contribute to underground weather.

Even caves without any direct contact with the outside world can still experience climatic variations, as they are subject to fluctuations in atmospheric pressure and geothermal activity, where the heat from Earth's core emanates through the rocky floor. However, in such caves, changes are more evenly distributed so take place over longer time frames.

Here, fog clouds can be seen in the deep sinkhole at the entrance of the caves while the Sun shines above it

Sizing up Cloud Ladder Hall



© Robbie Shone

Predicting the weather

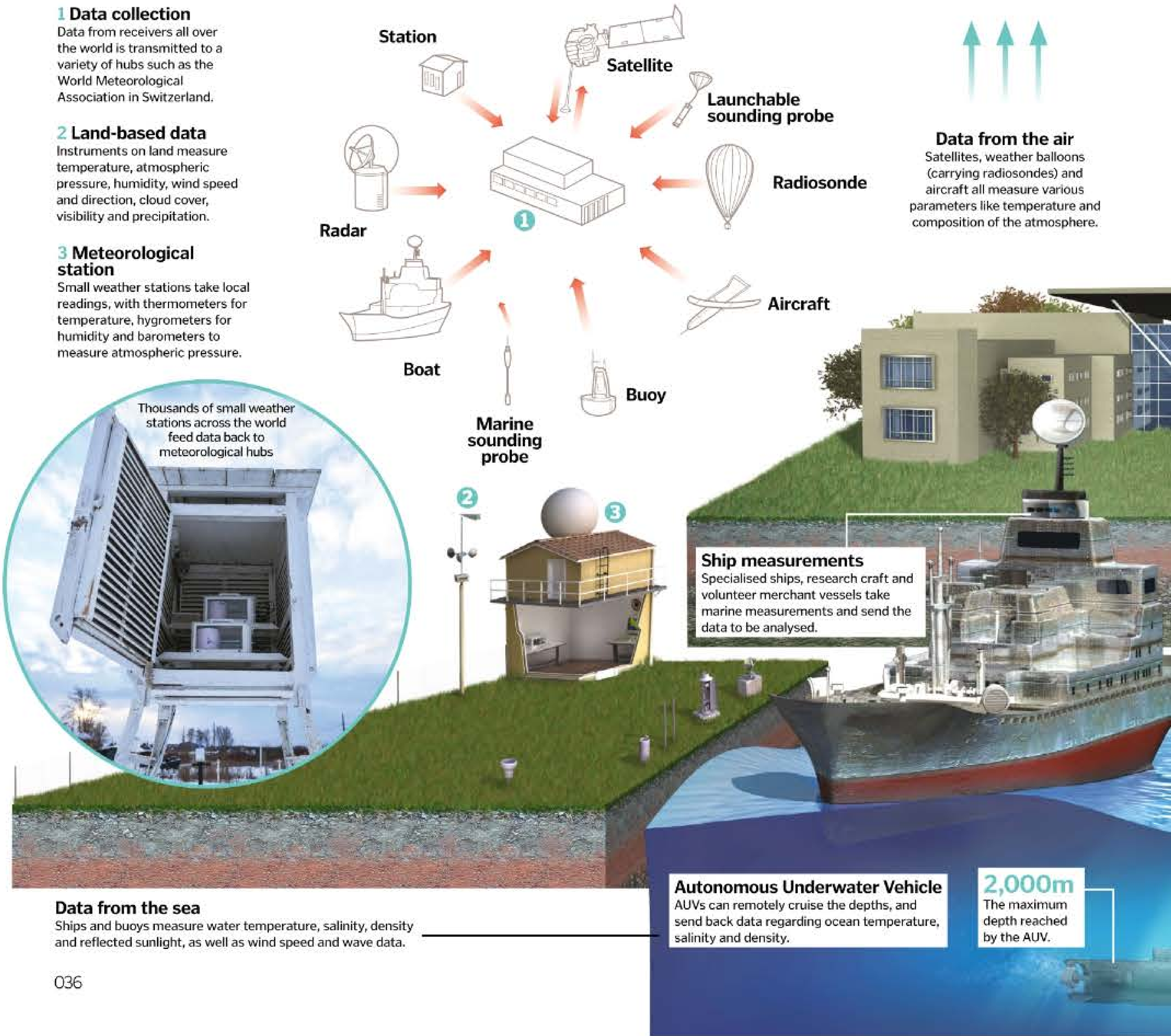
Discover the method that helps us prepare for the elements, come rain or shine

The weather affects us all, every day. From governing the difference between life and death, to providing a conversation topic to fill awkward silences at a party, it is an ever-present and ever-changing part of life. This means that predicting it accurately is a hugely important task.

In the UK, the Met Office is responsible for weather monitoring and prediction. Before a forecast can be put together, measurements from thousands of data recorders across the world are collected and analysed. Every day, around 500,000 observations are received, including atmospheric measurements from land and sea, satellites, weather balloons and aircraft. But, this is still not enough to represent the weather in every location.

To fill in the gaps, the data is assimilated. This combines current data with what is expected, to provide the best estimate of the atmospheric conditions. To produce an accurate forecast, the data has to be fed into a supercomputer that creates a numerical model of the atmosphere. The process involves many complex equations, and the Met Office's IBM supercomputer can do more than 1,000 trillion calculations a second, running an atmospheric model with a million lines of code.

Forecasters can use this data and techniques such as nowcasting – using estimates of current weather speed and direction – to predict the weather in the hours ahead. For longer range forecasts, further computer models are relied upon.



1 Data collection
Data from receivers all over the world is transmitted to a variety of hubs such as the World Meteorological Association in Switzerland.

2 Land-based data
Instruments on land measure temperature, atmospheric pressure, humidity, wind speed and direction, cloud cover, visibility and precipitation.

3 Meteorological station
Small weather stations take local readings, with thermometers for temperature, hygrometers for humidity and barometers to measure atmospheric pressure.

Data from the air
Satellites, weather balloons (carrying radiosondes) and aircraft all measure various parameters like temperature and composition of the atmosphere.

Thousands of small weather stations across the world feed data back to meteorological hubs

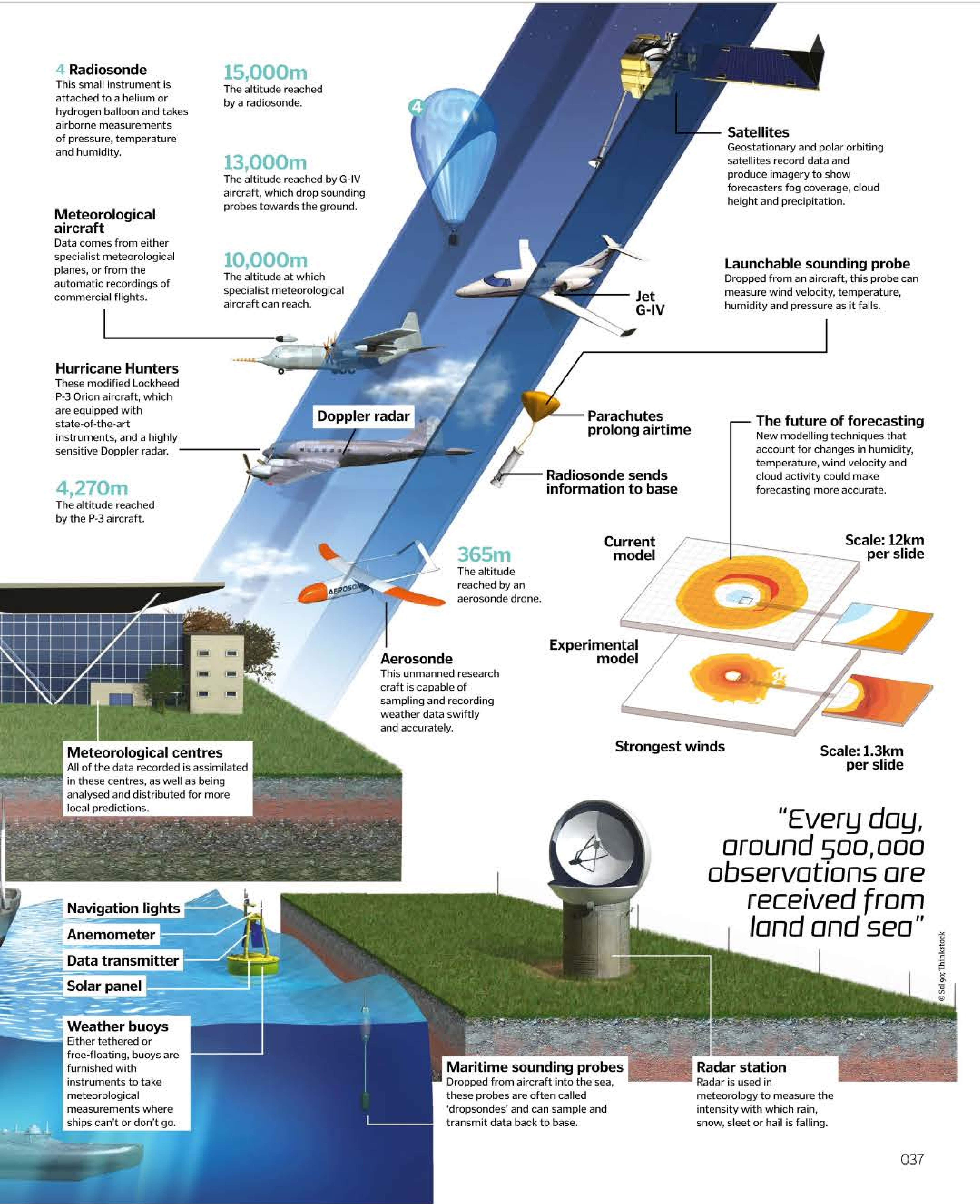
Ship measurements
Specialised ships, research craft and volunteer merchant vessels take marine measurements and send the data to be analysed.

Autonomous Underwater Vehicle
AUVs can remotely cruise the depths, and send back data regarding ocean temperature, salinity and density.

2,000m
The maximum depth reached by the AUV.

Data from the sea
Ships and buoys measure water temperature, salinity, density and reflected sunlight, as well as wind speed and wave data.

DID YOU KNOW? In 300 BCE, Greek philosopher Theophrastus wrote a book listing over 200 ways to forecast weather



4 Radiosonde
This small instrument is attached to a helium or hydrogen balloon and takes airborne measurements of pressure, temperature and humidity.

15,000m
The altitude reached by a radiosonde.

13,000m
The altitude reached by G-IV aircraft, which drop sounding probes towards the ground.

Meteorological aircraft
Data comes from either specialist meteorological planes, or from the automatic recordings of commercial flights.

10,000m
The altitude at which specialist meteorological aircraft can reach.

Hurricane Hunters
These modified Lockheed P-3 Orion aircraft, which are equipped with state-of-the-art instruments, and a highly sensitive Doppler radar.

4,270m
The altitude reached by the P-3 aircraft.

Satellites
Geostationary and polar orbiting satellites record data and produce imagery to show forecasters fog coverage, cloud height and precipitation.

Launchable sounding probe
Dropped from an aircraft, this probe can measure wind velocity, temperature, humidity and pressure as it falls.

365m
The altitude reached by an aerosonde drone.

Aerosonde
This unmanned research craft is capable of sampling and recording weather data swiftly and accurately.

The future of forecasting
New modelling techniques that account for changes in humidity, temperature, wind velocity and cloud activity could make forecasting more accurate.

Meteorological centres
All of the data recorded is assimilated in these centres, as well as being analysed and distributed for more local predictions.

> *"Every day, around 500,000 observations are received from land and sea"*

Weather buoys
Either tethered or free-floating, buoys are furnished with instruments to take meteorological measurements where ships can't or don't go.

Maritime sounding probes
Dropped from aircraft into the sea, these probes are often called 'dropsondes' and can sample and transmit data back to base.

Radar station
Radar is used in meteorology to measure the intensity with which rain, snow, sleet or hail is falling.

© Sol90; Thinkstock

Lightning

Capable of breaking down the resistance of air, lightning is a highly visible discharge of electricity capable of great levels of destruction. But how is it formed?

Intense upthrust of volcanic particles can help generate lightning

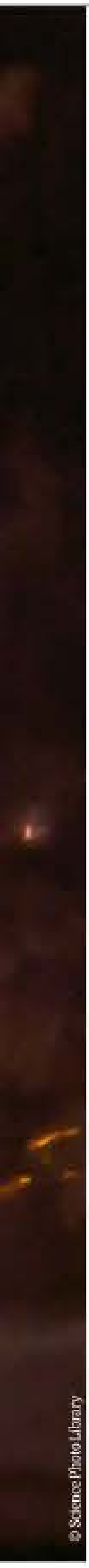
Lightning occurs when a region of cloud attains an excess electrical charge, either positive or negative, that is powerful enough to break down the resistance of the surrounding air. This process is typically initiated by a preliminary breakdown within the cloud between its high top region of positive charge, large central region of negative charge and its smaller lower region of positive charge.

The different charges in the cloud are created when water droplets are supercooled within it to freezing temperatures and then collide with ice crystals. This process causes a slight positive charge to be transferred to the smaller ice crystal particles and a negative one to the larger ice-water mixture, with the former rising to the top on updrafts and the latter falling to the bottom under the effect of gravity. The consequence of this is gradual separation of charge between the upper and lower parts of the cloud.

This polarisation of charges forms a channel of partially ionised air – ionised air is that in which neutral atoms and molecules are converted to electrically charged ones – through which an initial lightning stroke (referred to as a 'stepped leader') propagates down through towards the ground. As the stepped leader reaches the Earth, an upwards connecting discharge of the opposing polarity meets it and completes the connection, generating a return stroke that due to the channel now being the path of least resistance, returns up through it to the cloud at one-third the speed of light and creating a large flash in the sky.

This leader-return stroke sequence down and up the ionised channel through the air commonly occurs three or four times per lightning strike, faster than the human eye is capable of perceiving. Furthermore, due to the massive potential difference between the charge areas – often extending from an incredible ten to 100 million volts – the return stroke can hold currents up to 30,000 amperes and reach heights of 30,000°C (54,000°F). Typically the leader stroke reaches the ground in just ten milliseconds and the return stroke reaches the instigating cloud in 100 microseconds.

DID YOU KNOW? *The peak temperature of a lightning bolt's return-stroke channel is 30,000°C (54,000°F)*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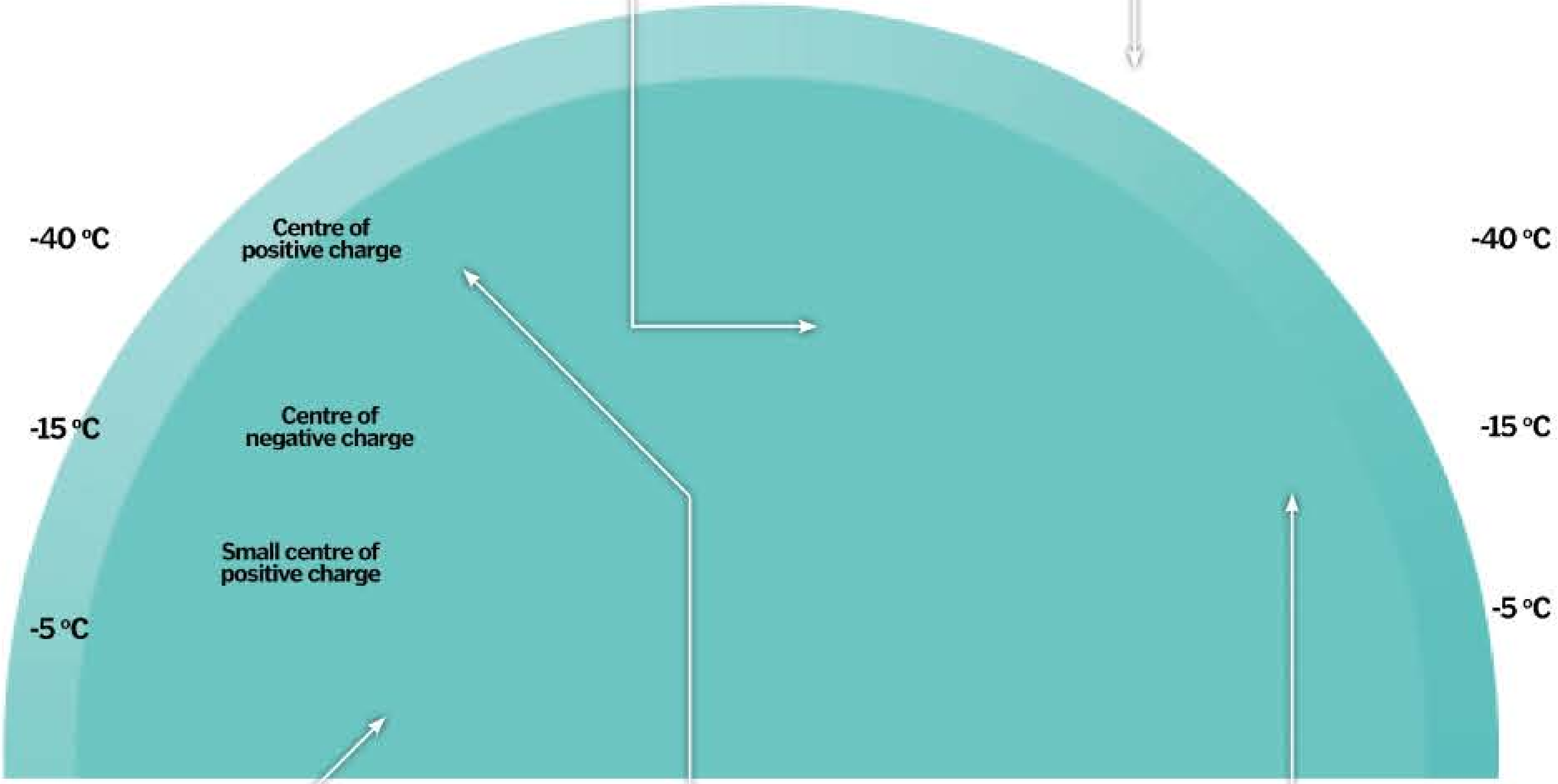
Explaining the formation of lightning


-40 °C
Centre of positive charge
-15 °C
Centre of negative charge
Small centre of positive charge
-5 °C
-40 °C
-15 °C
-5 °C

Cloud-to-cloud
As with cloud-to-ground, cloud-to-cloud lightning discharges occur between polarised areas of differing charge, however here the ionised channel runs between clouds instead of a cloud to the ground.

Cloud-to-air
Similar to cloud-to-cloud, cloud-to-air strikes tend to emanate from the top-most area of a cloud that is positively charged, discharging through an ionised channel directly into the air.

Cloud-to-ground
Cloud-to-ground lightning occurs when a channel of partially ionised air is created between areas of positive and negative charges, causing a lightning stroke to propagate downward to the ground.

Intra-cloud
Intra-cloud lightning is the most frequent type worldwide and occurs between areas of differing electrical potential within a single cloud. It is responsible for most aeroplane-related lightning disasters.

Charge differential
Clouds with lightning-generating potential tend to consist of three layers of charge, with the top-most part a centre of positive charge, the middle a centre of negative charge, and the bottom a secondary small centre of positive charge.

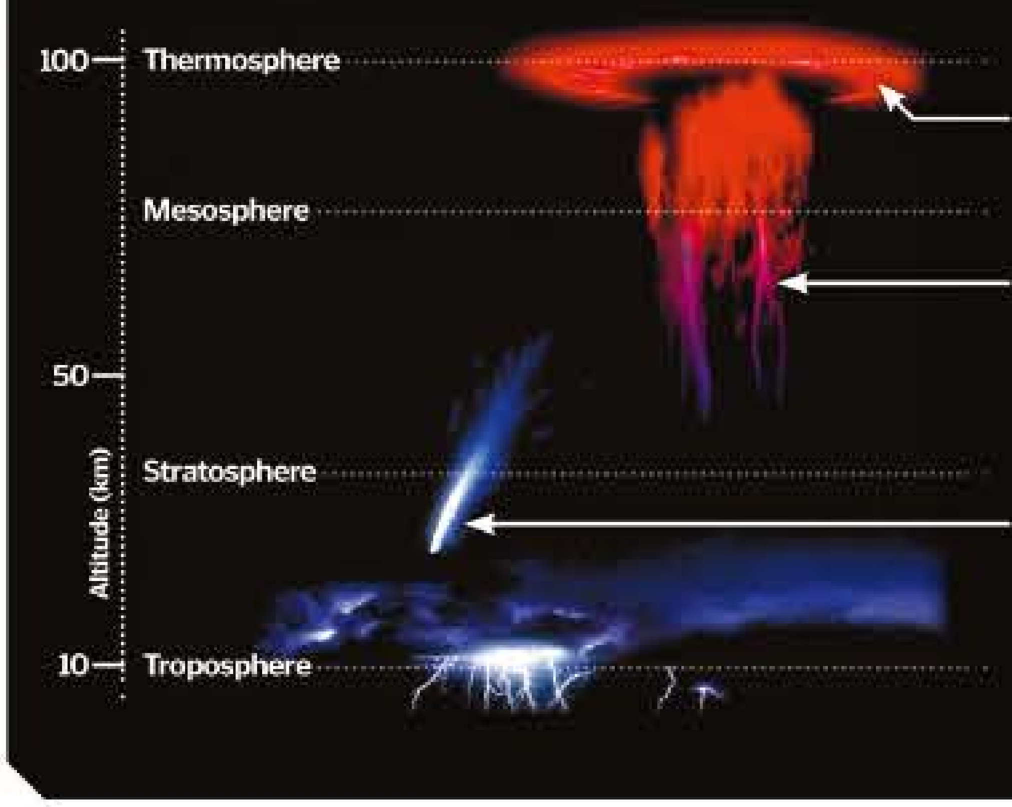
Lightning, however, does not just occur between clouds (typically cumulonimbus or stratiform) and the ground, but also between separate clouds and even intra-cloud. In fact, 75 per cent of all lightning strikes worldwide are cloud-to-cloud or intra-cloud, with discharge channels forming between areas of positive and negative charges between and within them. In addition, much lightning occurs many miles above the Earth in its upper atmosphere (see 'Atmospheric lightning' boxout), ranging from types that emanate from the top of clouds, to those that span hundreds of miles in width.

Despite the high frequency of lightning strikes and their large amount of contained energy, current efforts by the scientific community to harvest its power have been fruitless. This is mainly caused by the inability of modern technology to receive and store such a large quantity of energy in such a short period of time, as each strike discharges in mere milliseconds. Other issues preventing lightning's use as an energy source include its sporadic nature – which while perfectly capable of striking the same place twice, rarely does – and the difficulties involved in converting high-voltage electrical power delivered by a strike into low-voltage power that can be stored and used commercially.

> *"Due to the massive potential difference between charge areas the return stroke can hold currents up to 30,000 amperes and reach 30,000°C (54,000°F)"*

Atmospheric lightning

Unseen apart from by satellites, a major part of the world's annual lightning is generated in Earth's upper atmosphere.



Elves
Vast 250-mile wide flattened discs of light, elves occur above low-lying thunderstorms. They are caused by the excitation of nitrogen molecules due to electron collisions in the atmosphere.

Sprites
Sprites are caused by the discharges of positive lightning from thunderclouds to the ground. They vary in colour from red to blue and appear akin to large jellyfish.

Blue jets
Emanating from the top of cumulonimbus clouds and stretching in a cone shape up into the stratosphere and mesosphere, blue jets are caused by intense hail activity within a storm.

Lightning types

Far from uniform, lightning is an unpredictable phenomenon

Bead lightning

A type of cloud-to-ground lightning where the strike seems to break up into smaller, super-bright sections (the beads), lasting longer than a standard discharge channel.

Frequency: **Rare**

Ribbon lightning

Only occurring in storms with high cross winds and multiple return strokes, ribbon lightning occurs when each subsequent stroke is blown to the side of the last, causing a visual ribbon effect.

Frequency: **Quite rare**

Staccato lightning

A heavily branched cloud-to-ground lightning strike with short duration stroke and incredibly bright flash.

© Scotto Bear

Frequency: **Common**

Sheet lightning

A generic term used to describe types of cloud-to-cloud lightning where the discharge path of the strike is hidden from view, causing a diffuse brightening of the surrounding clouds in a sheet of light.

© Christian Arntzen

Frequency: **Common**

Megalightning

A term commonly used when referring to upper-atmospheric types of lightning. These include sprites, blue jets and elves (see 'Atmospheric lightning' boxout) and occur in the stratosphere, mesosphere and thermosphere.

Frequency: **Frequent**

Ball lightning

Considered as purely hypothetical by meteorologists, ball lightning is a highly luminous, spherical discharge that according to few eyewitnesses last multiple seconds and can move on the wind.

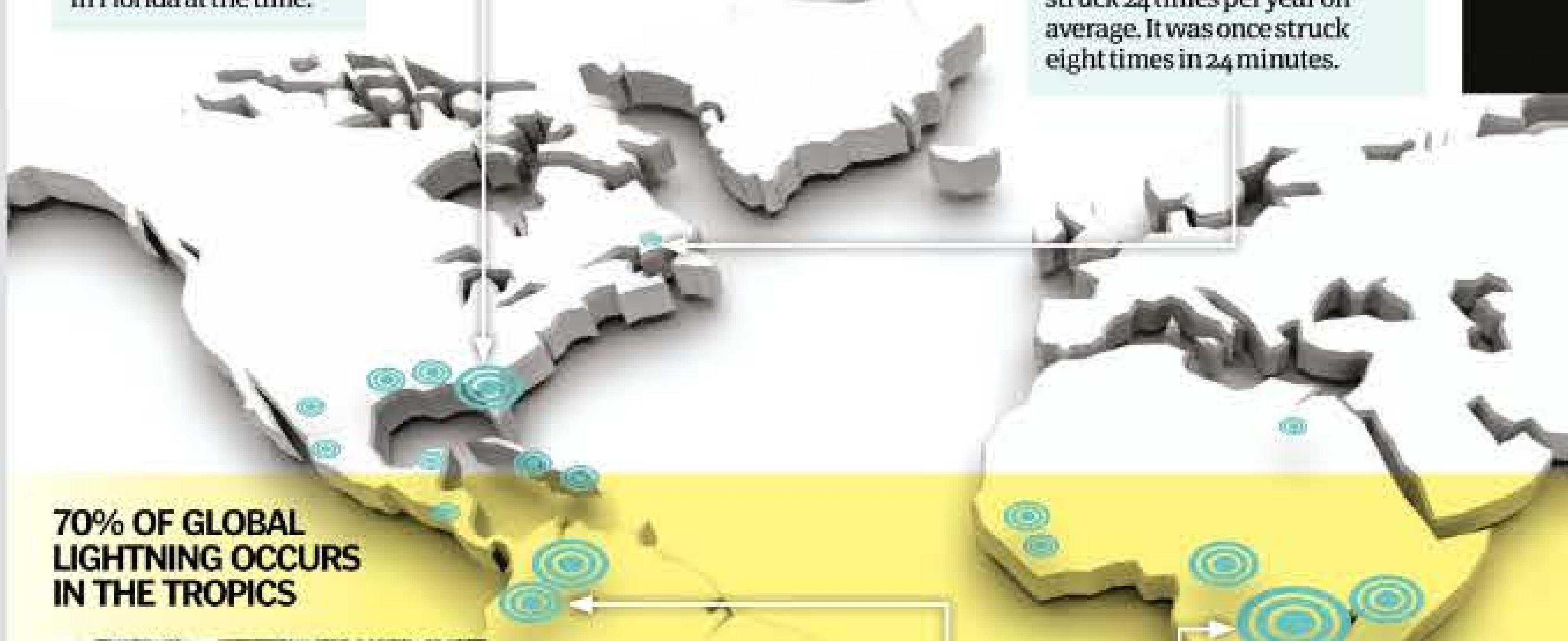
Frequency: **Very rare**

Lightning hotspots

A look at some of the most dangerous places to be when lightning strikes

Danger zone
Ten per cent of all people struck by lightning were in Florida at the time.

Multiple strikes
The Empire State Building is struck 24 times per year on average. It was once struck eight times in 24 minutes.



70% OF GLOBAL LIGHTNING OCCURS IN THE TROPICS

'Damn! And to think that tree was just two months from retirement'

© Thechemicalengineer

Flashes
Above the Catatumbo River in Venezuela lightning flashes several times per minute 160 nights of the year.

Global hotspot
The small village of Kifuka is the most struck place on Earth, with 158 strikes per square kilometre per year.

What are the chances?

The odds of being hit by lightning aren't as slim as you think…

1 in 300,000

The chance of you getting struck by lightning is one in 300,000. Which, while seeming quite unlikely, did not stop US park ranger Roy Sullivan from being struck a world record seven times during his lifetime.

DID YOU KNOW? *The irrational fear of lightning is referred to as astraphobia*

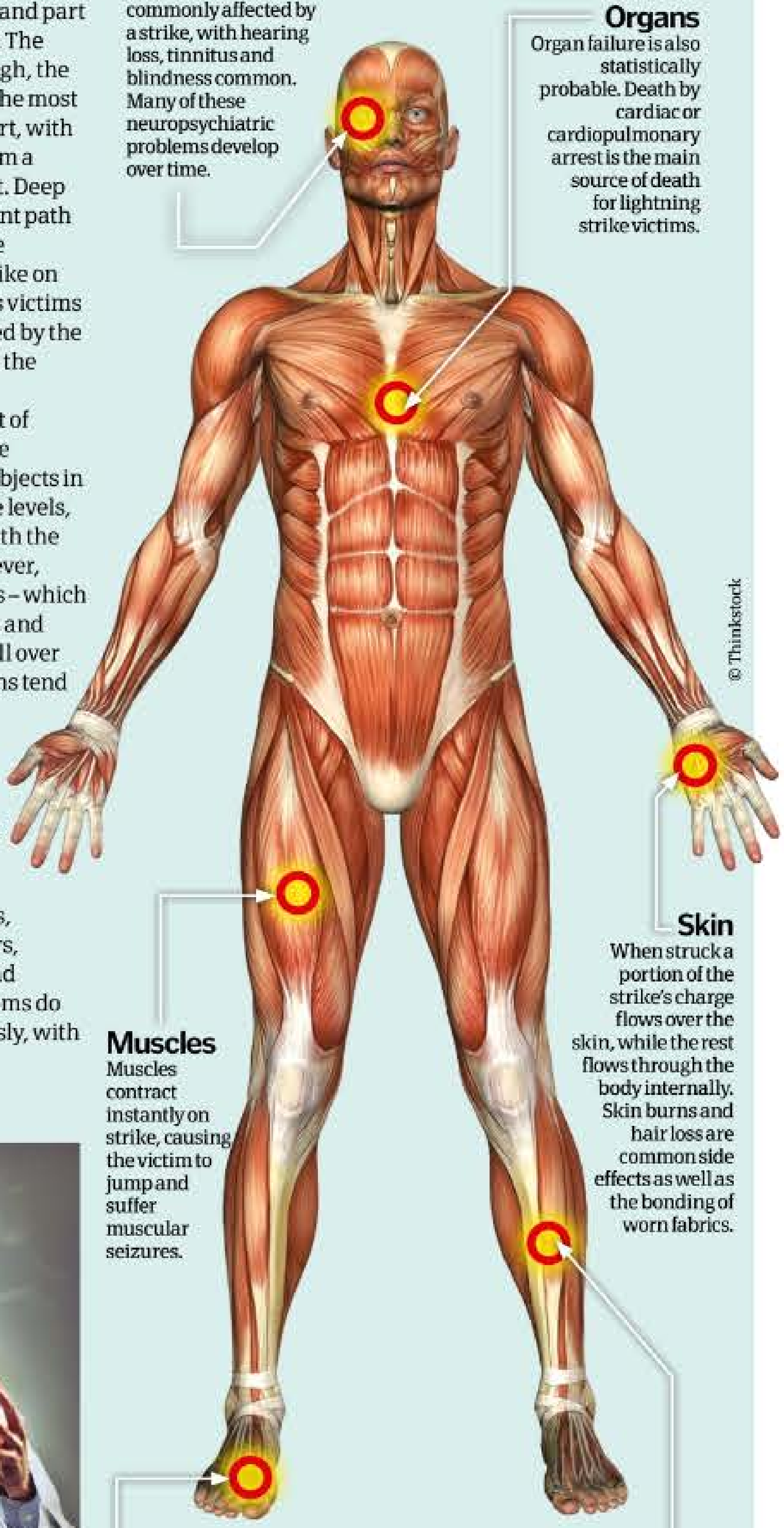
What happens when you get struck by lightning?

The parts of the body that feel the effect if struck by lightning

When a human is hit by lightning, part of the strike's charge flows over the skin – referred to as external flashover – and part of it goes through them internally. The more of the strike that flows through, the more internal damage it causes. The most common organ affected is the heart, with the majority of people who die from a strike doing so from cardiac arrest. Deep tissue destruction along the current path can also occur, most notably at the entrance and exit points of the strike on the body. Lightning also causes its victims to physically jump, which is caused by the charge contracting the muscles in the body instantaneously.

Burns are the most visible effect of being struck by lightning, with the electrical charge heating up any objects in contact with the skin to incredible levels, causing them to melt and bond with the human's skin. Interestingly, however, unlike industrial electrical shocks – which can last hundreds of milliseconds and tend to cause widespread burns all over the body – lightning-induced burns tend to be centred more around the direct point of contact, with a victim's head, neck and shoulders most affected.

Post-strike side-effects of being struck by lightning range from amnesia, seizures, motor control damage, hearing loss and tinnitus, through blindness, sleep disorders, headaches, confusion, tingling and numbness. Further, these symptoms do not always develop instantaneously, with many – notably neuropsychiatric problems (vision and hearing) – developing over time.



Audio visual
Eyes and ears are commonly affected by a strike, with hearing loss, tinnitus and blindness common. Many of these neuropsychiatric problems develop over time.

Organs
Organ failure is also statistically probable. Death by cardiac or cardiopulmonary arrest is the main source of death for lightning strike victims.

Skin
When struck a portion of the strike's charge flows over the skin, while the rest flows through the body internally. Skin burns and hair loss are common side effects as well as the bonding of worn fabrics.

Muscles
Muscles contract instantly on strike, causing the victim to jump and suffer muscular seizures.

Body tissue
Deep tissue destruction is common along the current path, which courses through the body from cranium to feet.

Nervous system
Motor control damage is common, often permanently affecting muscle and limb movement, neural circuitry and motor planning and execution decisions.

© Thinkstock

© Science Photo Library

Cloud-to-cloud lightning streaks across the Masai Mara Game Reserve in Kenya, Africa

© Science Photo Library

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Deadly
In July 2007, 30 people were killed by lightning in the remote village of Ushari Dara in northwestern Pakistan.

Singapore strikes!
Singapore has one of the world's highest rates of lightning activity.

in comparison…

1 in 14,000,000
The chance of winning the lottery in the UK is one in 14 million. That is over 45 times as unlikely as being struck.

1 in 12,000,000
The odds of getting hit by lightning are 40 times more likely than the chance of dying from Mad Cow Disease in the UK.

1 in 11,000,000
Flying on a single-trip commercial air flight inflicts you to a one in 11 million chance of being killed in an accident.

1 in 8,000
In order to get better odds, go out in your car. Over 3,000 people are killed every day on roads worldwide.

Firestorms

From tornado-force winds to superhot flames, dare you discover nature's most violent infernos?

DID YOU KNOW? *Large wildfires have increased by 300 per cent in western USA since the mid-Eighties*

Firestorms are among nature's most violent and unpredictable phenomena. Tornado-force winds sweep superhot flames of up to 1,000 degrees Celsius (1,800 degrees Fahrenheit) through buildings and forests alike. Victims often suffocate before they can flee and entire towns can be obliterated. Survivors of firestorms describe darkness, 100-metre (330-foot)-high fireballs and a roaring like a jumbo jet. To give you an idea of the sheer heat, firestorms can be hot enough to melt aluminium and tarmac, warp copper and even turn sand into glass.

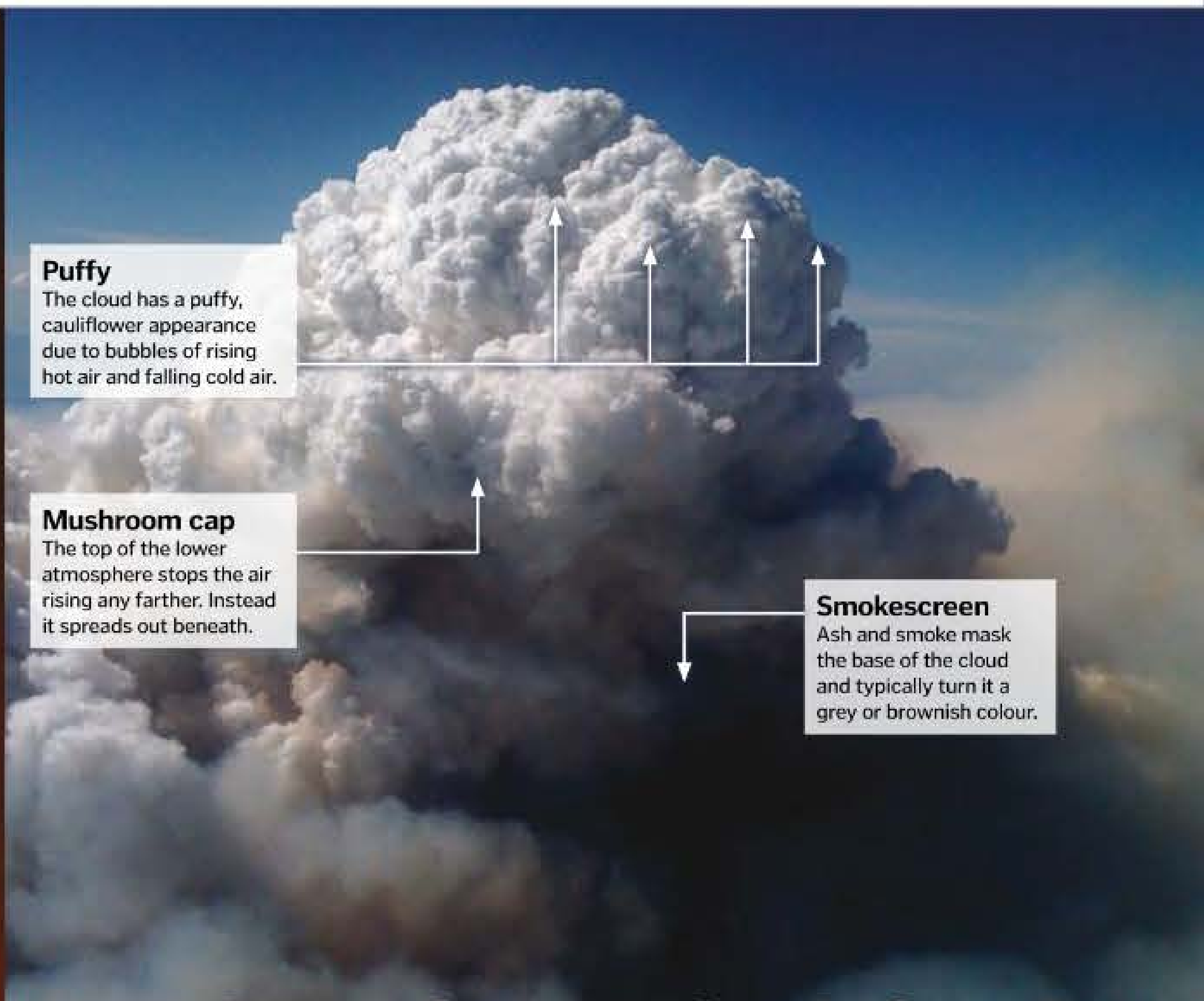
Firestorms happen worldwide, especially in the forests of the United States and Indonesia, and in the Australian bush. They occur mostly in summer and autumn when vegetation is tinder dry. Although they are a natural phenomenon, among the most devastating were triggered deliberately. During World War II, for instance, Allied forces used incendiaries and explosives to create devastating firestorms in Japanese and German cities. Firestorms also erupted after the cataclysmic meteor impact of 66 million years ago that many believe to have triggered the extinction of the dinosaurs.

Climate change may be already increasing the risk of mega-fires by making summers ever hotter and drier. The Rocky Mountain Climate Organization, for example, has reported that from 2003 to 2007, the 11 western US states warmed by an average of one degree Celsius (1.8 degrees Fahrenheit). The fire danger season has gone up by a staggering 78 days since 1986.

The risk of an Australian firestorm striking a major city has also heightened in the last 40 years. Climate change may have exacerbated this by increasing the risk of long heat waves and extremely hot days. In January 2013 alone, a hundred bushfires raged through the states of New South Wales, Victoria and Tasmania following a record-breaking heat wave. Maximum daily temperatures rose to 40.3 degrees Celsius (104.5 degrees Fahrenheit), beating the previous record set in 1972.

Firestorms can happen during bush or forest fires, but are not simply wildfires. Indeed, a firestorm is massive enough to create its own weather (see boxout). The thunderstorms, powerful winds and fire whirls – mini tornadoes of spinning flames – it can spawn are all part of its terrifying power.

The intense fire can have as much energy as a thunderstorm. Hot air rises above it, sucking in additional oxygen and dry debris, which fuel and spread the fire. Winds can reach tornado speed – tens of times the ambient wind speeds. The huge pillar of rising air – called a



Puffy
The cloud has a puffy, cauliflower appearance due to bubbles of rising hot air and falling cold air.

Mushroom cap
The top of the lower atmosphere stops the air rising any farther. Instead it spreads out beneath.

Smokescreen
Ash and smoke mask the base of the cloud and typically turn it a grey or brownish colour.

How do mushroom clouds form?

The terrifying mushroom clouds produced after nuclear bombs are examples of pyrocumulus, or fire, clouds. This towering phenomenon is caused by intense ground heating during a firestorm. Their tops can reach an incredible nine kilometres (six miles) above the ground. When the fire heats the air, it rises in a powerful updraft that lifts water vapour, ash and dust. The vapour starts to cool high in the atmosphere and condenses as water droplets on the ash. As a result, a cloud forms that can quickly become a thunderstorm with lightning and rain, if enough water is available. The lightning can start new fires, but on the bright side, rain can extinguish them.

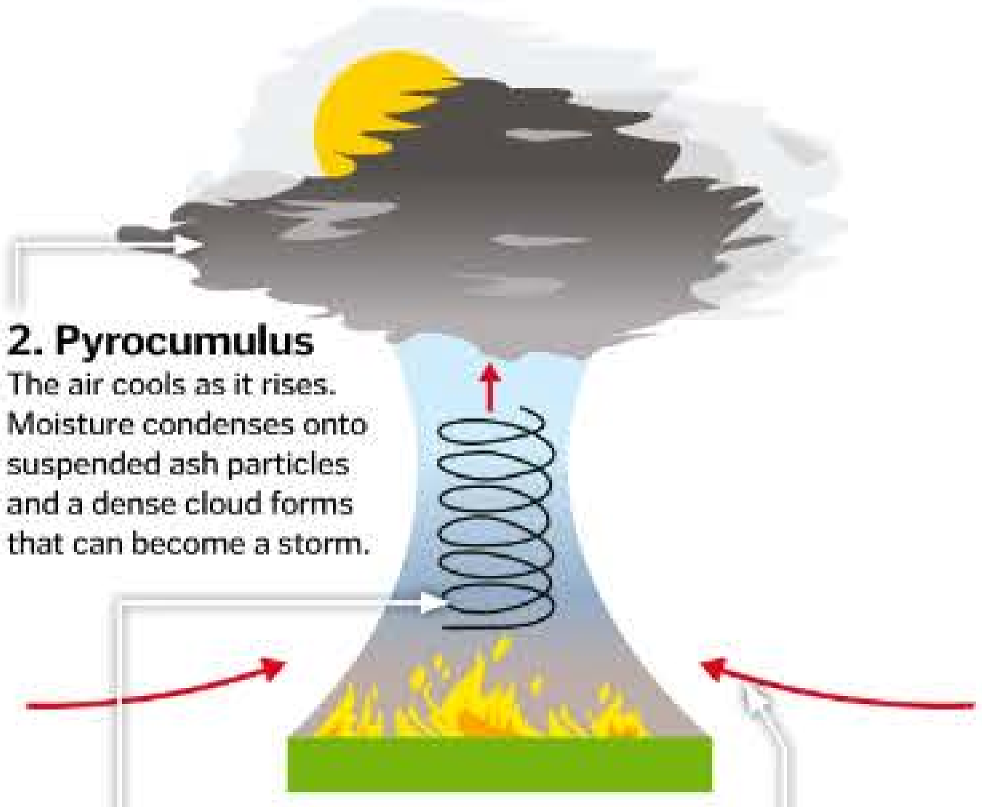
How firestorms change the weather

Firestorms can release as much energy as a lightning storm on a hot summer's afternoon.

Warm air above the fire is lighter than the surrounding air so it rises; the swirling pillar of lifting air above the fire is called a thermal column. This tornado-like structure is responsible for a firestorm's power. Under the right weather conditions, air can rise inside the column at eye-watering speeds of 270 kilometres (170 miles) per hour!

Cooler air gusts into the space left behind by the ascending air, causing violent winds that merge fires together into a single intense entity. They also blow in oxygen, wood and other flammable material that serve to fuel and intensify the blaze.

Turbulent air spiralling around the thermal column can spawn fire tornadoes and throw out sparks. These can set light to trees and houses tens of metres away, increasing the conflagration's range.



2. Pyrocumulus
The air cools as it rises. Moisture condenses onto suspended ash particles and a dense cloud forms that can become a storm.

1. Thermal column
The fire warms the air above, causing it to become lighter than its surroundings so it rises.

3. Filling the gap
Air rushes into the space left by the rising air, creating violent gusts that only intensify the fire.

thermal column – swirling above the firestorm can generate thunderclouds and even lightning strikes that spark new fires.

The thermal column, in turn, can spawn a number of fiery tornadoes, which can tower to 200 metres (650 feet) and stretch 300 metres (980 feet) wide, lasting for at least 20 minutes. These fling flaming logs and other burning debris across the landscape, spreading the blaze. The turbulent air can gust at 160 kilometres (100 miles) per hour, scorching hillsides as far as 100 metres (330 feet) away from the main fire. It's far more powerful than a typical wildfire, which moves at around 23 kilometres (14.3 miles) per hour – just under the average human sprint speed.

Like all fires, firestorms need three things to burn. First is a heat source for ignition and to dry fuel so it burns easier. Fuel, the second must, is anything that combusts, whether that be paper, grass or trees. Thirdly, all fires need at least 16 per cent oxygen to facilitate their chemical processes. When wood or other fuel burns, it reacts with oxygen in the surrounding air to release heat and generate smoke, embers and various gases. Firestorms are so intense that they often consume all available oxygen, suffocating those who try to take refuge in ditches, air-raid shelters or cellars.

Fighting firestorms

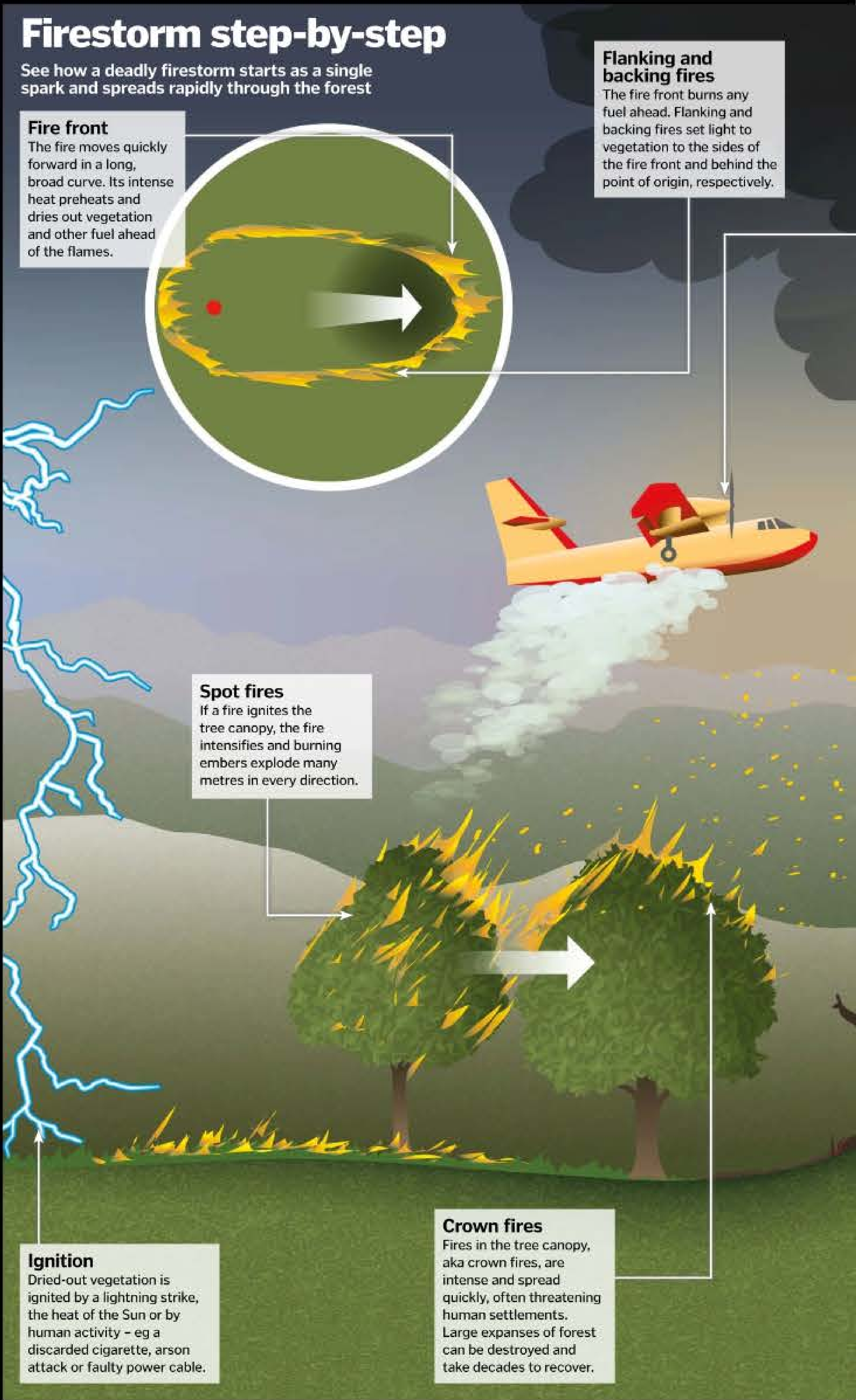
Fire wardens, air patrols and lookout stations all help detect fires early, before they can spread. Once a fire starts, helicopters and air tankers head to the scene. They spray thousands of gallons of water, foam or flame-retardant chemicals around the conflagration. In the meantime, firefighters descend by rope or parachute to clear nearby flammable material.

We can reduce the risk of fire breaking out in the first place by burning excess vegetation under controlled conditions. Surprisingly this can actually benefit certain plants and animals. Canadian lodgepole pines, for example, rely partly on fire to disperse their seeds. Burning also destroys diseased trees and opens up congested woodland to new grasses and shrubs, which provides grazing for cattle and deer.

Vegetation in fire-prone areas often recovers quickly from a blaze. Plants like Douglas fir, for instance, have fire-resistant bark – although it can only withstand so much heat. Forest owners help flora to return by spreading mulch, planting grass seed and erecting fences.

Firestorm step-by-step

See how a deadly firestorm starts as a single spark and spreads rapidly through the forest



Fire front
The fire moves quickly forward in a long, broad curve. Its intense heat preheats and dries out vegetation and other fuel ahead of the flames.

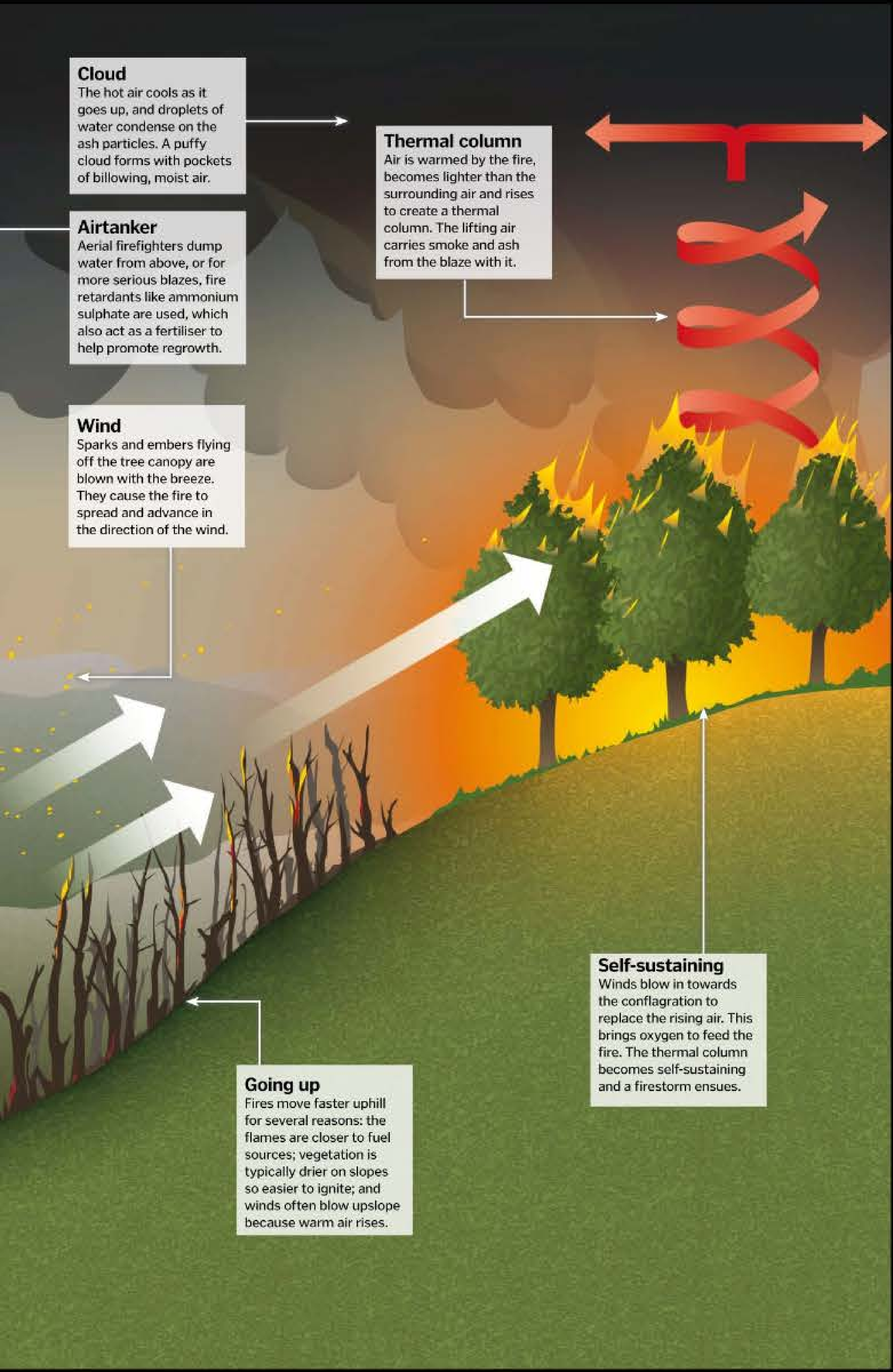
Flanking and backing fires
The fire front burns any fuel ahead. Flanking and backing fires set light to vegetation to the sides of the fire front and behind the point of origin, respectively.

Spot fires
If a fire ignites the tree canopy, the fire intensifies and burning embers explode many metres in every direction.

Ignition
Dried-out vegetation is ignited by a lightning strike, the heat of the Sun or by human activity – eg a discarded cigarette, arson attack or faulty power cable.

Crown fires
Fires in the tree canopy, aka crown fires, are intense and spread quickly, often threatening human settlements. Large expanses of forest can be destroyed and take decades to recover.

DID YOU KNOW? *The biggest man-made firestorm took place in Dresden, Germany, in 1945; 70 per cent of the city was destroyed*



Cloud
The hot air cools as it goes up, and droplets of water condense on the ash particles. A puffy cloud forms with pockets of billowing, moist air.

Airtanker
Aerial firefighters dump water from above, or for more serious blazes, fire retardants like ammonium sulphate are used, which also act as a fertiliser to help promote regrowth.

Wind
Sparks and embers flying off the tree canopy are blown with the breeze. They cause the fire to spread and advance in the direction of the wind.

Thermal column
Air is warmed by the fire, becomes lighter than the surrounding air and rises to create a thermal column. The lifting air carries smoke and ash from the blaze with it.

Self-sustaining
Winds blow in towards the conflagration to replace the rising air. This brings oxygen to feed the fire. The thermal column becomes self-sustaining and a firestorm ensues.

Going up
Fires move faster uphill for several reasons: the flames are closer to fuel sources; vegetation is typically drier on slopes so easier to ignite; and winds often blow upslope because warm air rises.

Five mega firestorms

1 Black Saturday

In 2009, one of Australia's worst bushfires killed 173 people, injured 5,000 more, destroyed 2,029 homes, killed a great number of animals and burnt 4,500 square kilometres (1,700 square miles) of land. Temperatures may have reached 1,200 degrees Celsius (2,192 degrees Fahrenheit).

2 Great Peshtigo

The deadliest fire in American history claimed 1,200-2,500 lives, burned 4,860 square kilometres (1,875 square miles) of Wisconsin and upper Michigan and destroyed all but two buildings in Peshtigo in 1871.

3 Ash Wednesday

More than 100 fires swept across Victoria and South Australia on 16 February 1983, killing 75 people, destroying 3,000 homes and killing 50,000 sheep and cows. It was the worst firestorm in South Australia's history.

4 Hamburg

This firestorm brought on by an Allied bomb strike in 1943 killed an estimated 44,600 civilians, left many more homeless and levelled a 22-square-kilometre (8.5-square-mile) area of the German city. Hurricane-force winds of 240 kilometres (150 miles) per hour were raised.

5 Great Kanto

A 7.9-magnitude earthquake on 1 September 1923 triggered a firestorm that burned up to 45 per cent of the city of Tokyo and killed over 140,000 people. This included 44,000 who were incinerated by a 100-metre (330-foot) fire tornado that ravaged the area.

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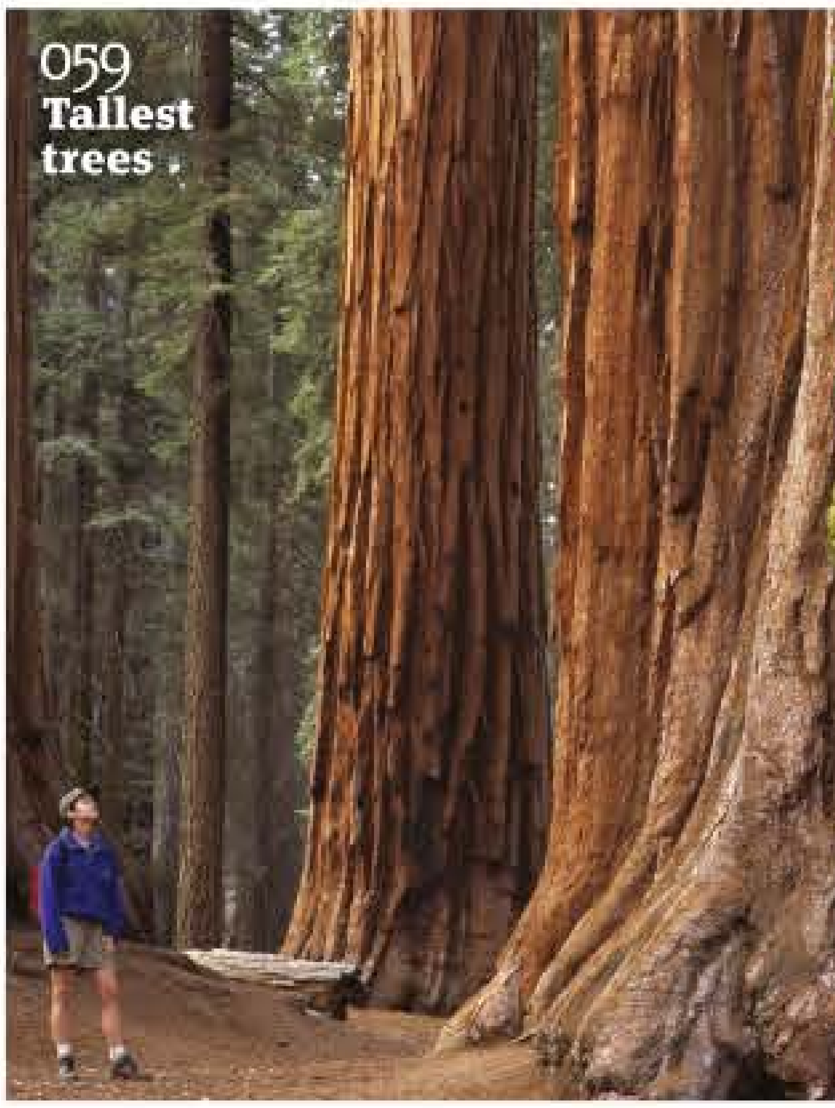
PLANTS & ORGANISMS

Cloning plants
061

How cacti survive
060



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Tallest trees

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048 How plants work
The incredible life cycle of a plant explained

052 Identifying leaves
Identify leaves of different trees with our guide

054 Poisonous plants
Discover which dangerous plants to avoid

056 The life of trees
Discover how trees grow and why you can't live without them

058 Woodland wildlife
Forests are home to many different creatures – how do they survive?

059 World's tallest trees
Do you know which tree beats the Statue of Liberty in height?

059 **The importance of trees**
The forest does more than provide firewood and scenic walks

060 **How do cacti live?**
The survival methods of these prickly flowers

061 **How are plants cloned?**
How identical copies of plants benefit us

062 **How do plants grow towards light?**
Getting enough sunlight

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How do these plants capture their live prey?

063 **Coffee plants**
From a seed to a steaming hot cup – how does it happen?

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Life of a tree

063 **How is coffee grown?**

© Ana_Labate

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Poisonous plants

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Deadliest plants

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A sunflower head comprises up to 2,000 tiny individual flowers

How plants work

Could you stay put in your birthplace for hundreds of years, surviving off whatever happens to be around?

Truly, it's not easy being green. But plants not only survive, they thrive all over the globe, without the benefit of muscles, brains or personalities. It's a good thing they do: plants head up nearly all food chains, pump out the oxygen we breathe, hold off erosion and filter pollutants out of the atmosphere. Over the past 3.5 billion years, they've diversified into an estimated 320,000-430,000 separate species, with more coming to light every year.

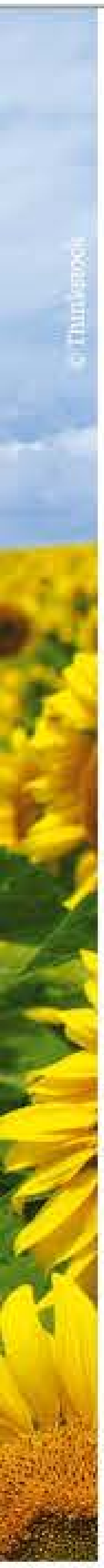
All this stems from one neat trick: harnessing the Sun's energy to power a built-in food factory. Through this process, called photosynthesis, plants combine carbon dioxide with water to create carbohydrates that they use to grow and reproduce. The earliest plants, similar to today's algae, didn't do much other than photosynthesise. They floated around in the ocean, soaking up water and rays and reproducing asexually. Then, around 500 million years ago, plants evolved to live on land, to obtain the power boost of more abundant sunlight. The first landlubber plants still needed to stay wet all over, however, so they were confined to perpetually damp areas. Today's mosses, liverworts, and hornworts have the same limitations.

Things got more exciting 90 million years later, when plants went vascular. Vascular plants have tissue structures that can distribute water and nutrients absorbed by one part of the body to the rest of the body. Instead of spending its days soaking in a puddle, a vascular plant can grow roots down into the ground to soak up water and minerals while sending shoots up into the dry air, topped with leaves that soak up sunshine to power the food factory. This feature allows vascular plants to evolve to a larger size.

Plants can store this food in their roots, in the form of root tubers, like carrots and sweet potatoes. Above ground, vascular plants protect themselves and retain their water supply with a waxy, waterproof covering called cuticle. Cuticle makes plants hearty enough to reach high into the air or spread far along the ground.

Plants grow at meristems, areas with cells that are capable of division – that is, making new cells. Hormones control this cell division to grow particular forms, like leaves, as well as controlling the direction of growth, guided by what the plant 'senses'. Based on the settling of starch grains that indicate the direction of gravity, the growth hormone auxin drives stems to grow up towards the sky and roots to grow down towards water. Then, plants actually turn leaves toward the Sun. Triggered by light-sensitive cells that effectively 'see' light, the

DID YOU KNOW? *Some seeds can lie dormant for years. In 1966, scientists successfully planted 10,000 year-old tundra lupine*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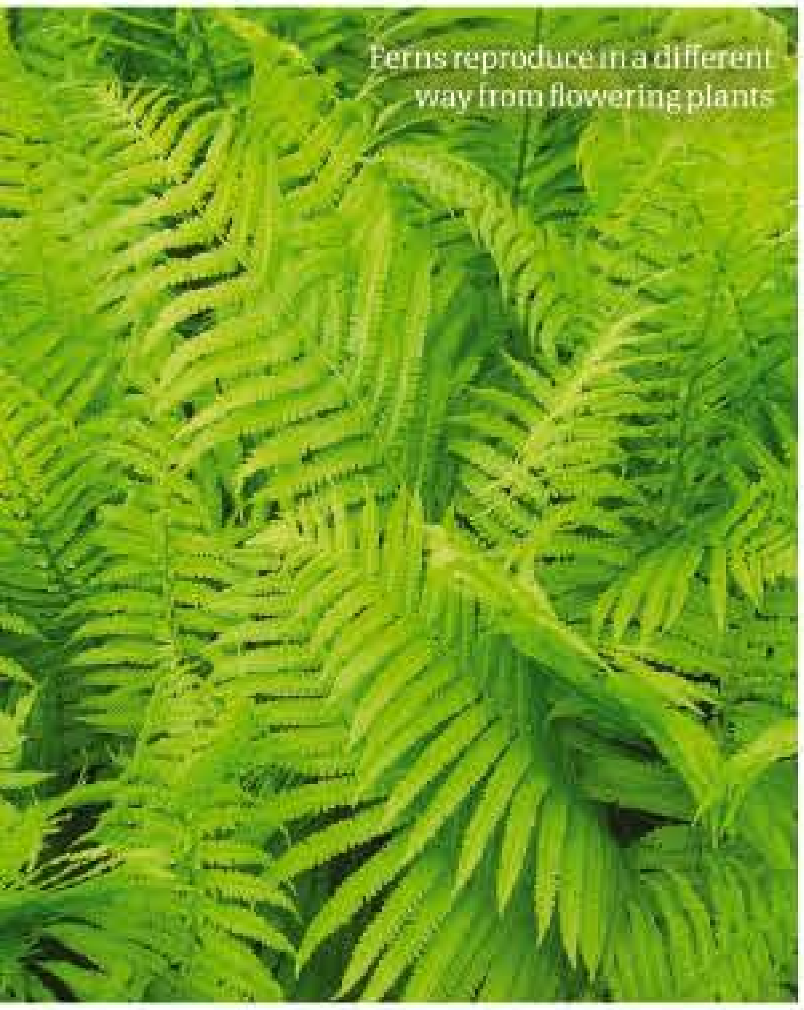
hormone auxin causes more cells to grow on the dimmer side of a stem, making the stem and attached leaf bend towards sunlight. Similarly, vines automatically curl when they come across a larger plant, causing them to wrap and climb.

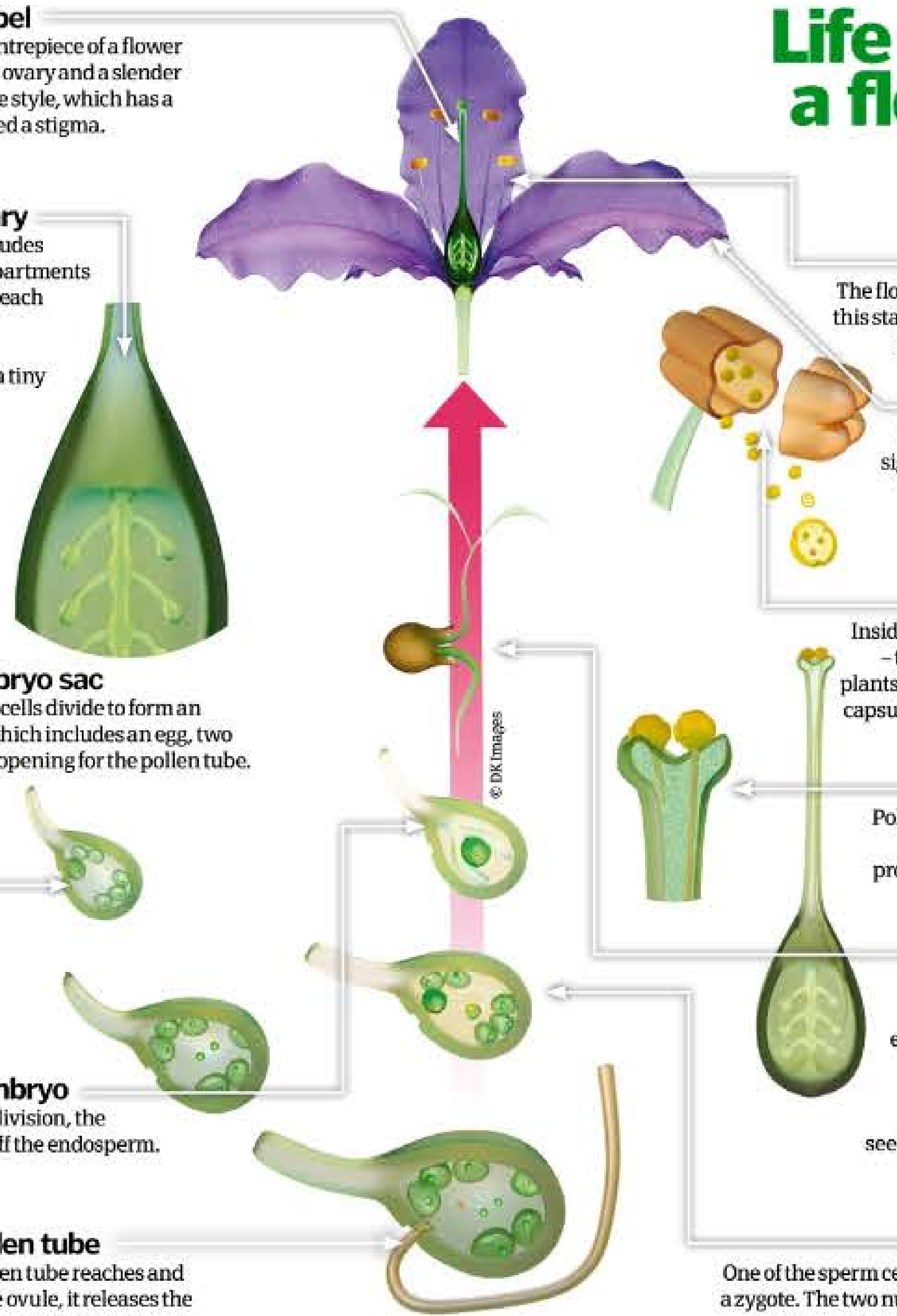
Plants switch sexual orientation every generation. Each sporophyte generation produces male and female spores, which asexually yield male and female plants. In this gametophyte generation, males produce sperm and females produce eggs, which join up to create new sporophyte plants. Typically, the sporophyte generation is a large, familiar plant, while the gametophyte generation is tiny. For example, pollen is tiny male plants in the gametophyte generation. The tiny males and females produce an embryo, or seed.

When you can't walk, spreading your seed requires a little more creativity. For example, flowering plants attract insects with nectar, and then coat their legs with pollen to carry to the next plant. Plants also develop tasty fruits around plant seeds to entice animals to swallow seeds, and then defecate those seeds miles away.

Plants enrich every corner of human life, even beyond food and oxygen. From invaluable herbs – plants with medicinal or flavour value – to towering trees made from woody tissue, our original go-to construction material, plants prop up our civilisation. High-five one today.


Ferns reproduce in a different way from flowering plants

Life cycle of a flowering plant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1. The carpel
The female centrepiece of a flower comprises the ovary and a slender neck called the style, which has a sticky top called a stigma.

2. The stamen
The flower's male members include this stalk-like filament, topped with the pollen-producing anther.

3. The petals
Flower petals are like a neon sign designed to attract insects that come for the free nectar, then unintentionally carry pollen to other flowers.

4. Gametophytes
Inside each anther, gametophytes – technically microscopic male plants – are encased in pollen grain capsules. Each includes two sperm cells and a tube cell.

5. The stigma
Pollen grains stick to the stigma at the tip of the carpel, and produce a pollen tube down the style and ovary.

6. The ovary
The ovary includes multiple compartments called ovules, each housing one gametophyte – technically, a tiny female plant.

7. The embryo sac
In each ovule, cells divide to form an embryo sac, which includes an egg, two nuclei and an opening for the pollen tube.

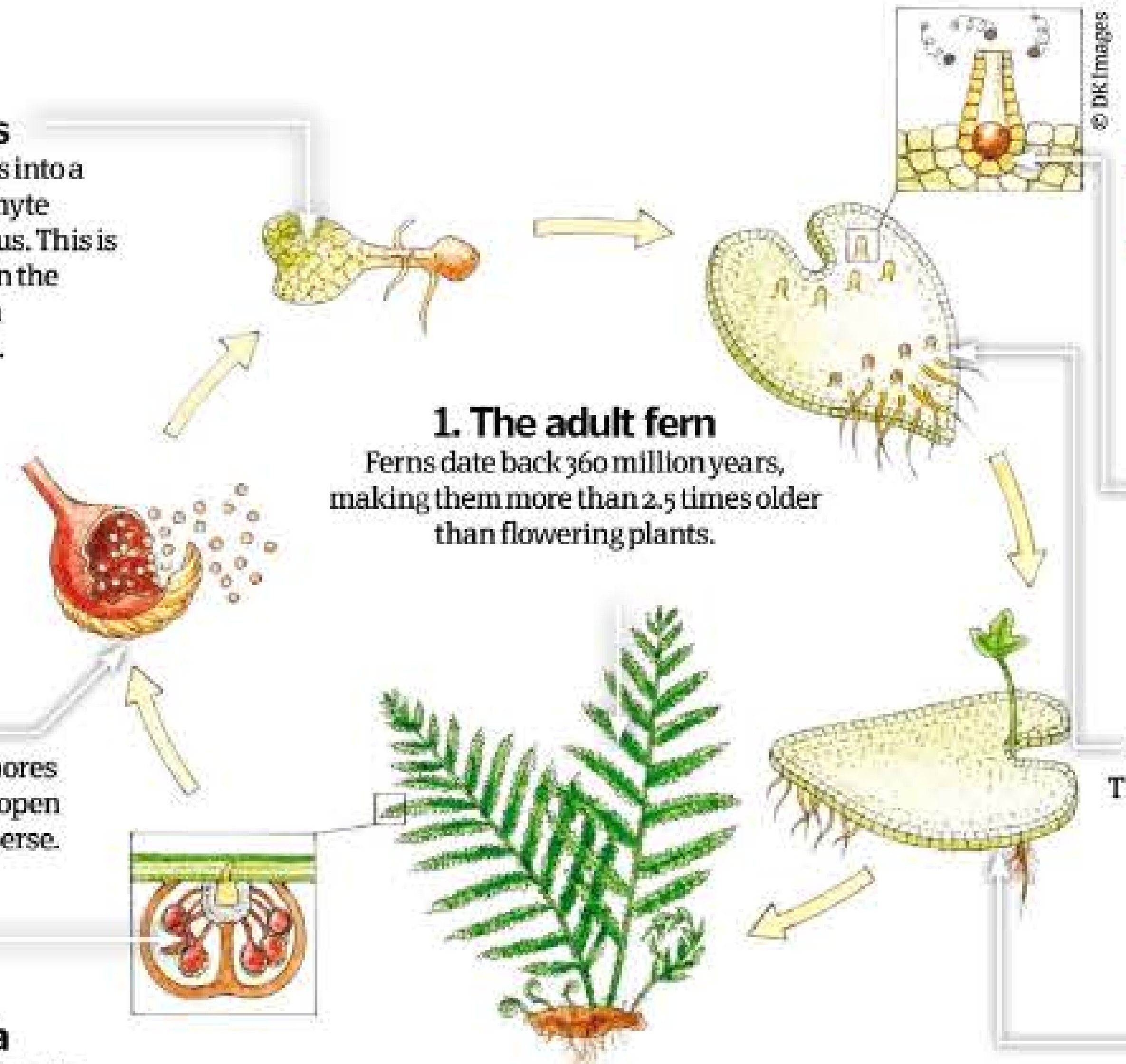
8. The pollen tube
When the pollen tube reaches and penetrates the ovule, it releases the two sperm cells into an embryo sac.

9. The zygote
One of the sperm cells fertilises the egg, creating a zygote. The two nuclei and the other sperm cell fuse to form a food supply called endosperm.

10. The embryo
Through cell division, the zygote feeds off the endosperm.

11. The seed
The casing surrounding the ovule hardens around the embryo, to form a seed. When it has ample warmth, moisture, and oxygen (typically in the spring), the seed germinates – that is, begins to grow into an adult plant.

Life cycle of a fern


© DK Images

1. The adult fern
Ferns date back 360 million years, making them more than 2.5 times older than flowering plants.

2. Sporangia
Inside these hard pods on the underside of fern fronds, spore cells multiply.

3. Spores
When enough spores form, they burst open the pod and disperse.

4. Prothallus
Each spore grows into a type of gametophyte called a prothallus. This is much bigger than the gametophytes in flowering plants.

5. Mature gametophyte
The prothallus grows both a female sex organ (the archegonia) and a male sex organ (the antherida), which produces sperm.

6. Archegonia
Sperm from another prothallus fertilises the egg inside the archegonia, to form a zygote.

7. Young fern
The zygote grows into a young fern, and the prothallus structure withers away.

Most unusual plants

The sensitive plant

Touch a leaf on the sensitive plant, also known as mimosa pudica, and an electrical current activates sudden water loss, causing leaves to drop abruptly. This imitation of an animal scares pests away.

Myrmecophytes

Many species, collectively known as myrmecophytes, have evolved to be ideal homes for ant colonies. In return, the ants viciously attack any threats to the plant.

Sumatran corpse flower

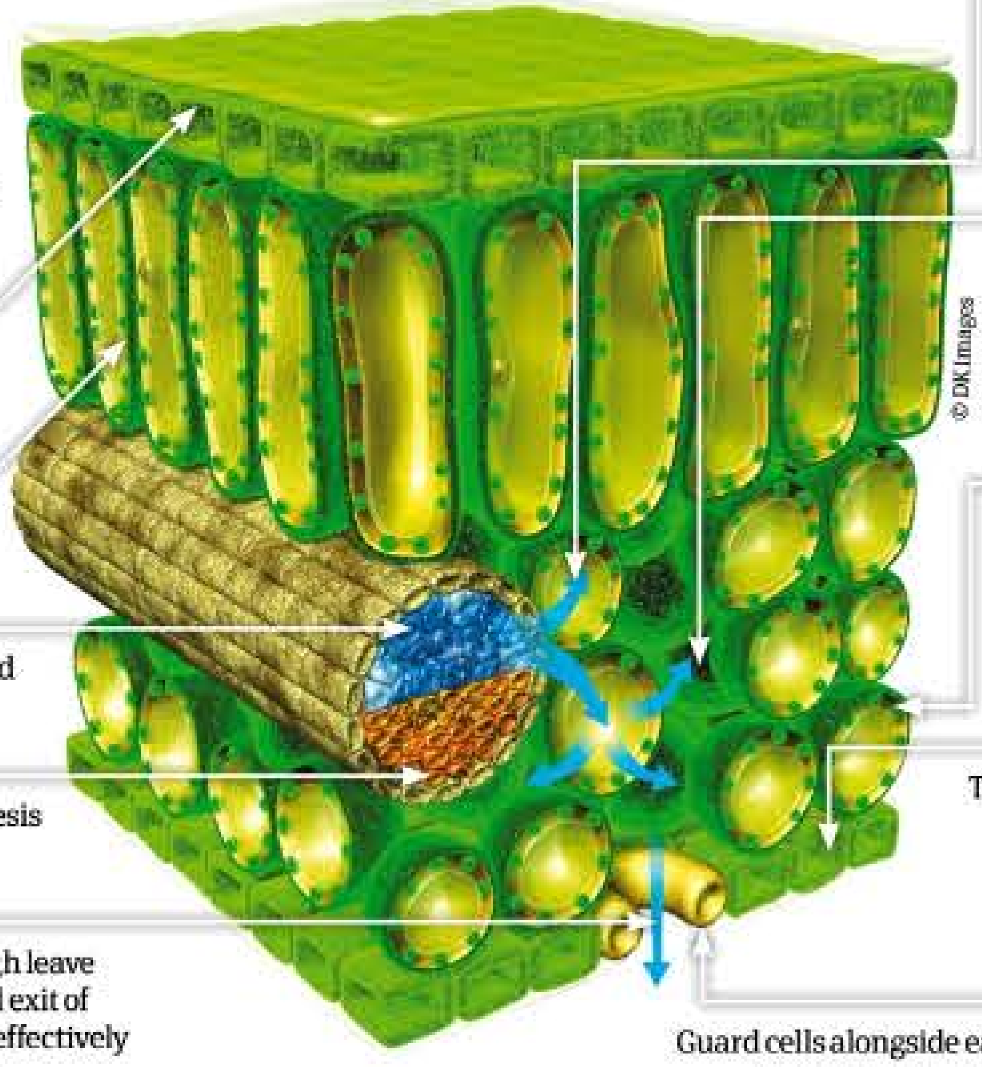
This flower can grow to be 0.9m (3ft) wide and 11 kilograms (24 pounds). It mimics the smell of rotting meat in order to attract carrion-eating insects, which then spread its pollen.

Snowdonia hawkweed

This Welsh flower is possibly the world's rarest plant. Botanists thought it extinct in the early-Fifties, but in 2002 it made a surprise reappearance near Bethesda.

Plant plumbing:
How transport works

Internal transportation systems in plants move water, food and other nutrients between roots, stems and leaves. This system is the key adaptation that allowed plants to evolve elaborate shapes and towering forms.



Upper epidermis
The waxy cuticle on the epidermis keeps the plant from drying out.

Palisade mesophyll
These cells are rich in chloroplasts, which are integral in photosynthesis.

Xylem vessel
These vessels carry water, with dissolved minerals, from the roots to leaves.

Phloem vessel
These carry food created in photosynthesis from leaves to the rest of the plant.

Diffusion
This water vapour exits the plant through leave openings called stomata. This continual exit of water creates negative pressure, which effectively pulls water up the xylem from the roots.

Movement of water
Water moves from the xylem vessels, which run from the roots to leaves, into the mesophyll cells.

Evaporation
Water along the walls of the mesophyll cells evaporates, forming water vapour.

Spongy mesophyll
Mesophyll cells fit together to form most of the tissue in a leaf.

Lower epidermis
The lower epidermis can be thinner than the upper epidermis, since it doesn't get direct sunlight.

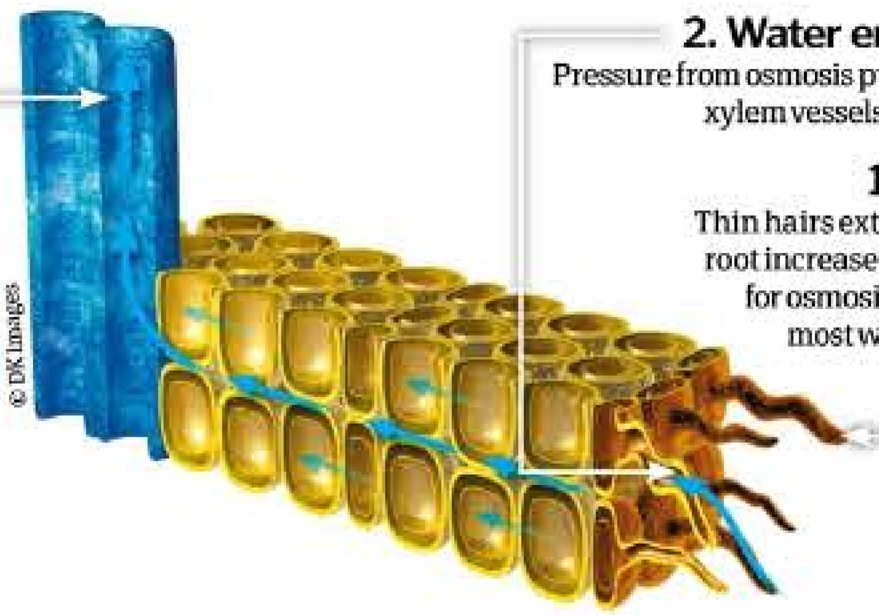
Stoma
Guard cells alongside each stoma (pore in the leaf) open when sunlight and humidity are high.

Flower stigmas come in various shapes

Insects seeking nectar pick up pollen on their legs

The root of it:
How absorption works

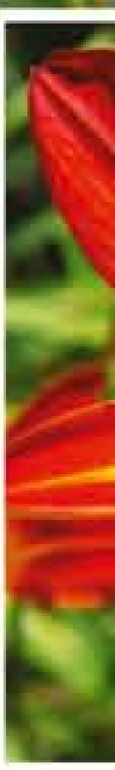
Roots soak up water through osmosis – the drive for water to move through a cell membrane from a less concentrated solution to a more concentrated solution, in order to achieve equilibrium. Cells in roots have a higher concentration than the surrounding water in the soil, so the water flows into the root.



3. Water enters the stem
Water continues flowing through the xylem, up into the above-ground stem, helped along by negative pressure in the leaves, created by evaporating water.

2. Water enters xylem
Pressure from osmosis pushes water into xylem vessels in the root core.

1. Root hairs
Thin hairs extending from the root increase the surface area for osmosis, and so handle most water absorption.

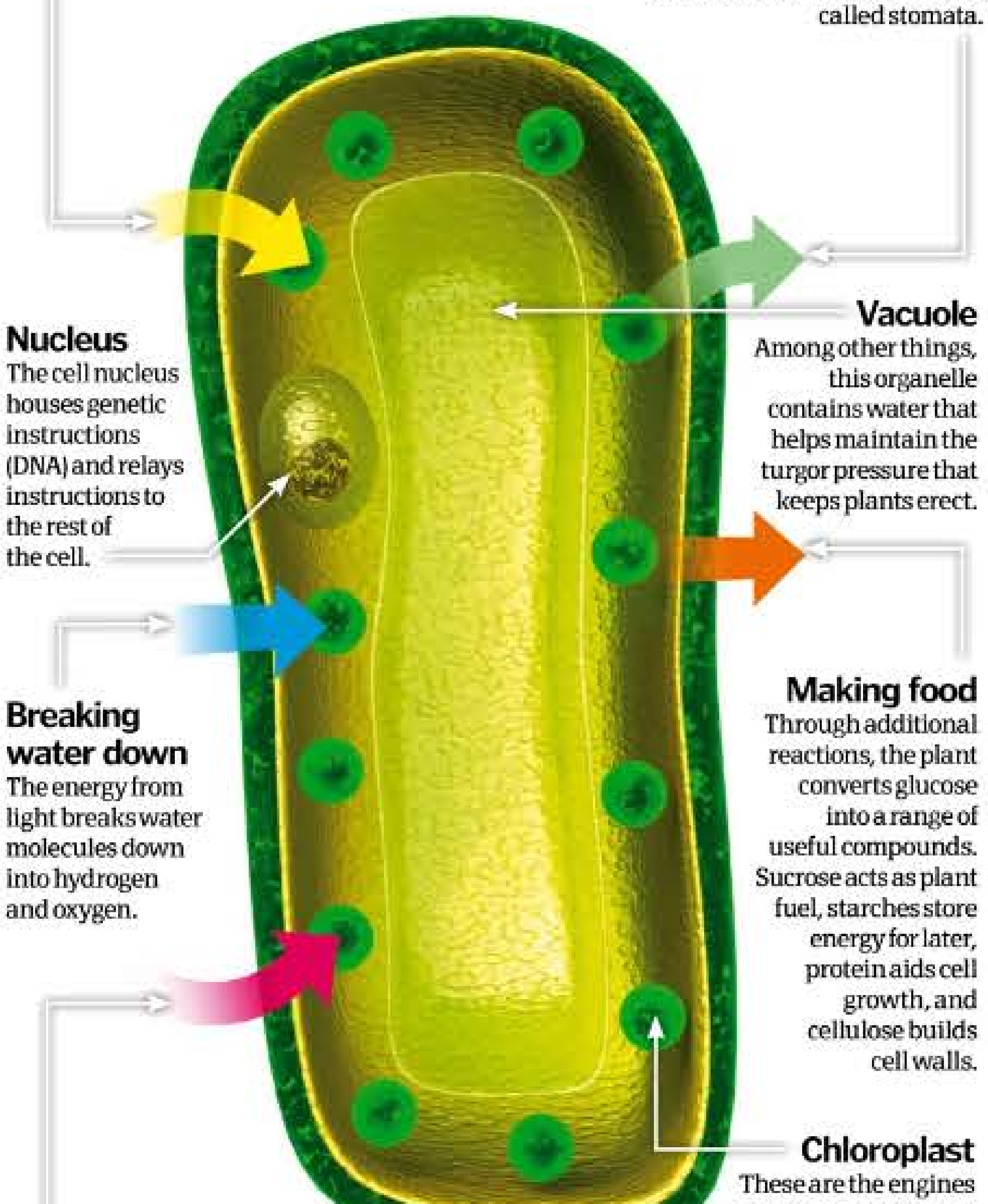


DID YOU KNOW? *We eat only about 200 of the 3,000 known rainforest fruits, while indigenous peoples use more than 2,000*

Inside the food factory: How photosynthesis works

In Greek, photosynthesis means 'putting together' (synthesis) using 'light' (photo), and that's a decent summary of what it's all about. However, photosynthesis doesn't actually turn light into food, as you sometimes hear; it's the power source for a chemical reaction that turns carbon dioxide and water into food.

The energy of light protons temporarily boosts the electrons in pigment molecules to a higher energy level. In other words, they generate an electrical charge. The predominant pigment in plants – chlorophyll – primarily absorbs blue, red, and violet light, while reflecting green light (hence, the green colour). In some leaves, chlorophyll breaks down in the autumn, revealing secondary pigments that reflect yellows, reds, and purples. Pigments are part of specialised organelles called chloroplasts, which transfer the energy of excited electrons in pigments to molecules and enzymes that carry out the photosynthesis chemical reaction.



Harnessing sunlight
Chlorophyll and other pigments absorb energy of light photons from the Sun.

Expelling oxygen
The oxygen from the water isn't necessary to make food, so the plant releases it through pores called stomata.

Nucleus
The cell nucleus houses genetic instructions (DNA) and relays instructions to the rest of the cell.

Vacuole
Among other things, this organelle contains water that helps maintain the turgor pressure that keeps plants erect.

Breaking water down
The energy from light breaks water molecules down into hydrogen and oxygen.

Making food
Through additional reactions, the plant converts glucose into a range of useful compounds. Sucrose acts as plant fuel, starches store energy for later, protein aids cell growth, and cellulose builds cell walls.

Chloroplast
These are the engines for photosynthesis. A typical leaf palisade cell includes up to 200 chloroplasts.

Adding carbon dioxide
Plants get all the CO2 they need from the air. CO2 combines with hydrogen to make glucose, a simple sugar.

© DK Images

Colourful petals are designed to attract insects

ON THE MAP

How much of the planet is covered by forest?

40 million sq km (15,444,100 sq miles), or a third of the Earth's land area, is covered by forests.

1 34% Rest of the world
2 20% Russian Federation
3 12% Brazil
4 8% US
5 8% Canada
6 5% China
7 4% Australia
8 3% Democratic Republic of Congo
9 2% India
10 2% Indonesia
11 2% Peru

mund 2009

Bunchberry dogwood

This shrub holds the 'fastest plant' record. When its flower opens, stamens fling out like a catapult, propelling pollen at 800 times the g-force astronauts experience.

Parachute flowers

The different species of parachute flower have long flower tubes lined with inward pointing hairs that temporarily hold insects trapped, to ensure they end up covered in pollen before exiting.

Welwitschia mirabilis

This so-called 'living fossil' plant of the Namib desert in Africa grows only two leaves, over hundreds of years. They grow continuously, however, and can extend more than 4 metres (13 feet).

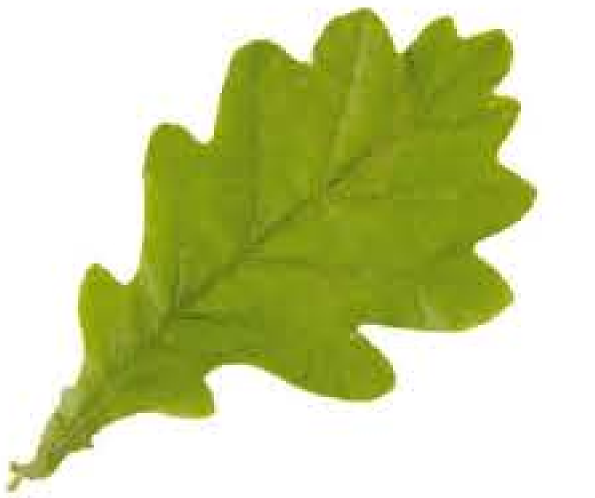
ience Photo Library

Flypaper plants

Also known as butterworts, these plants are coated in super-sticky digestive enzymes that absorb nutrients from all manner of bugs that happen to get trapped.

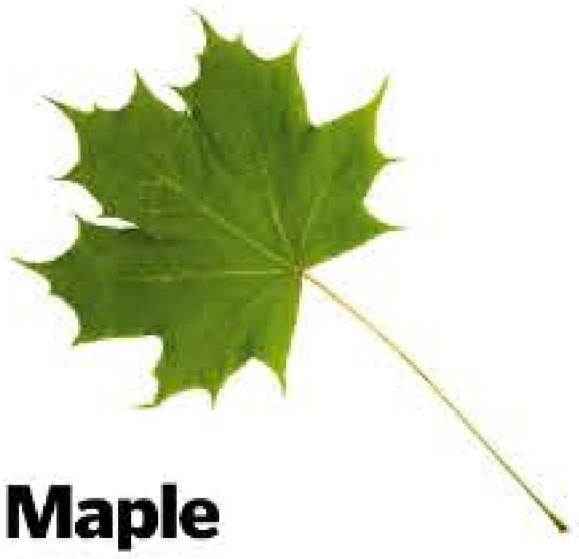
See the leaves for the trees

Yew willow become an expert at identifying leaves with our handy guide



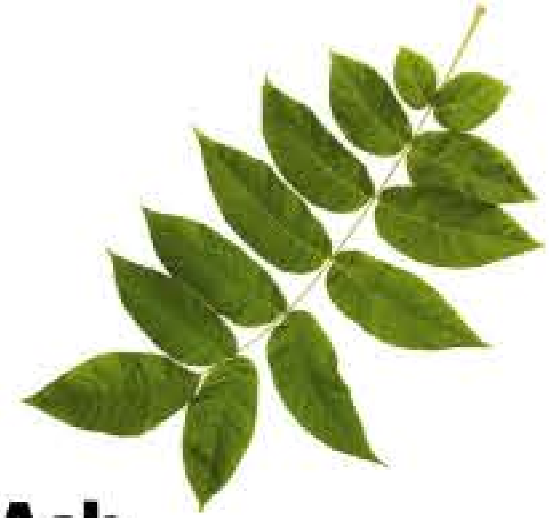
Oak

There are two main types of oak tree, the sessile oak and the pedunculate oak (which has a shorter stem). Oak leaves are used by the US Army as a rank symbol.



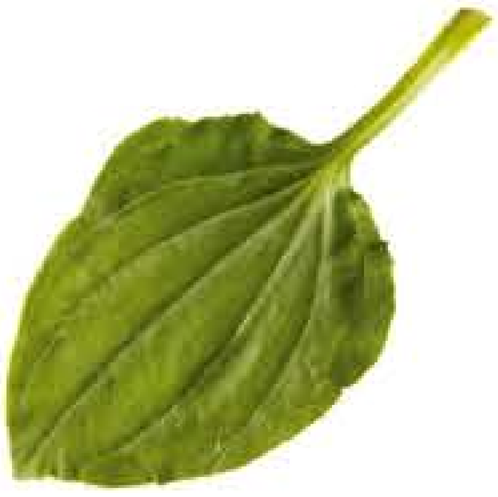
Maple

You might recognise this leaf from Canada's national flag. A maple tree's leaves usually have between three and nine lobes, and are arranged opposite one another on the branches.



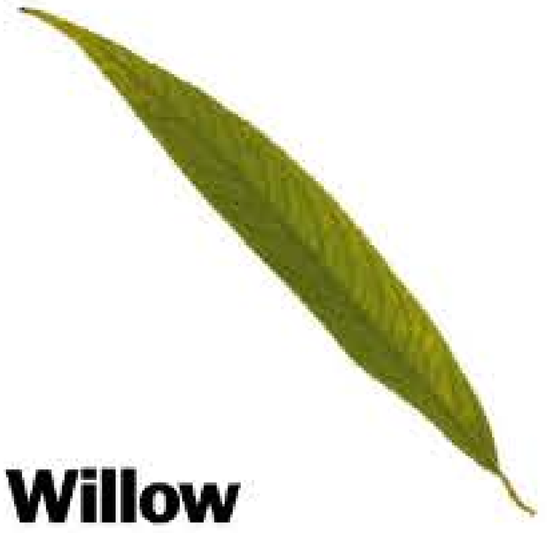
Ash

Ash leaves form in pairs; each central stem will bear nine to 13 leaflet pairs with one leaf at the tip. All leaves are pointed and toothed, and have tiny hairs on their lower surface.



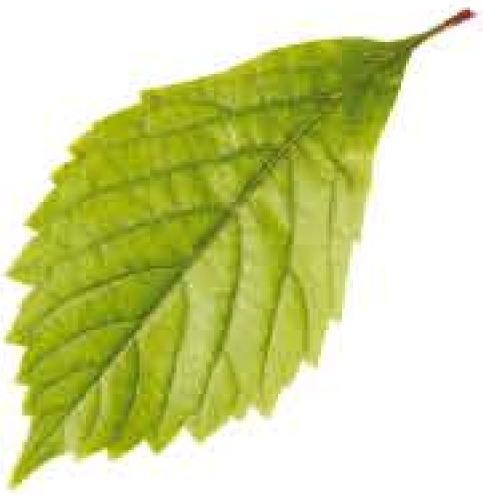
Plantain

These form in a rosette formation and range from five to thirty centimetres (two to 12 inches) in length. Generally, they are egg-shaped and are often hairless.



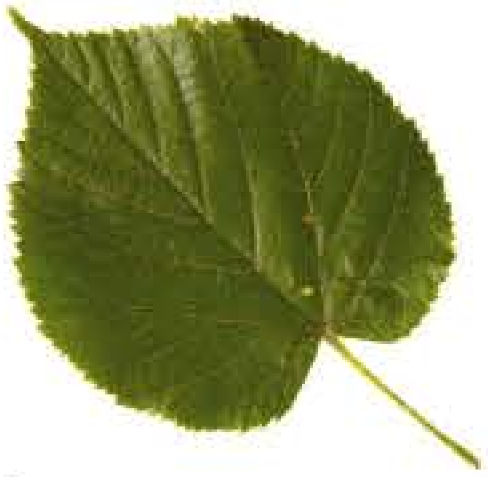
Willow

Willow leaves tend to be long and thin and will alternate along the stem. As they mature, they lose many of their minute hairs and become a duller green on top, while the underside remains silver.



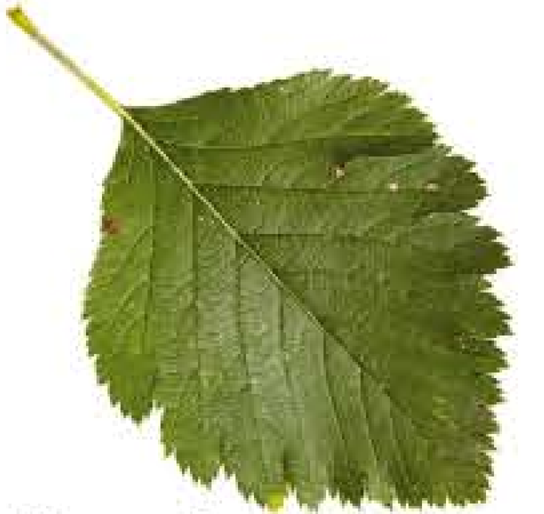
Alder

Each alder leaf will have six to eight pairs of veins which are quite sunken in appearance. These leaves remain on the tree until quite late in the year.



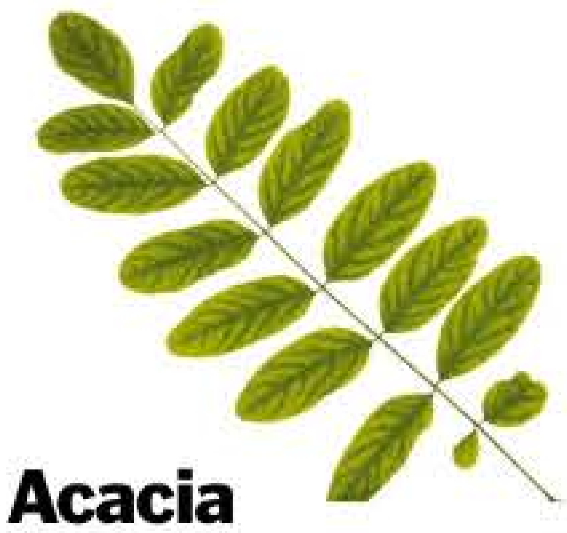
Lime

Lime leaves are generally heart-shaped and in an alternate arrangement. The margin is made up of tiny teeth and the underside has prominent veins protruding from its surface.



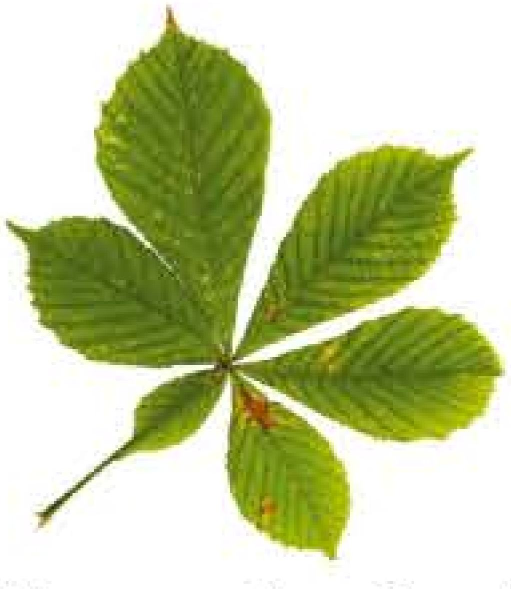
Hazel

Hazel leaves are almost completely round other than the section nearest the tip which is slightly pointed. It has a noticeable toothed edge with a hairy underside and stalk.



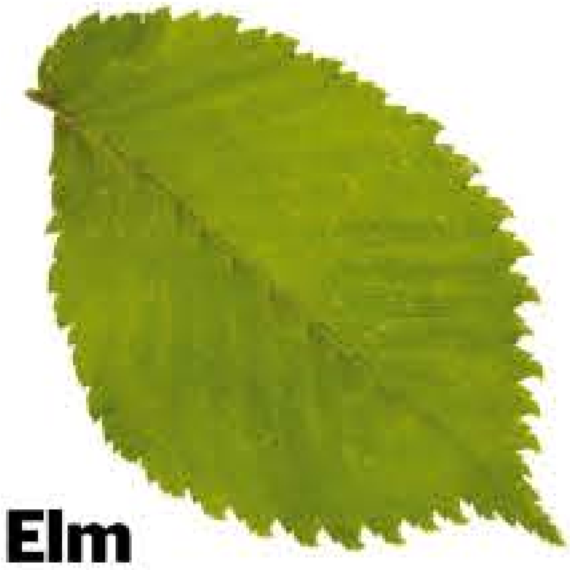
Acacia

Acacia leaves are classed as compound pinnate, as they form in pairs with a single leaflet at the end of the branch. In hotter countries, acacia stalks flatten to protect the leaves from intense sunlight.



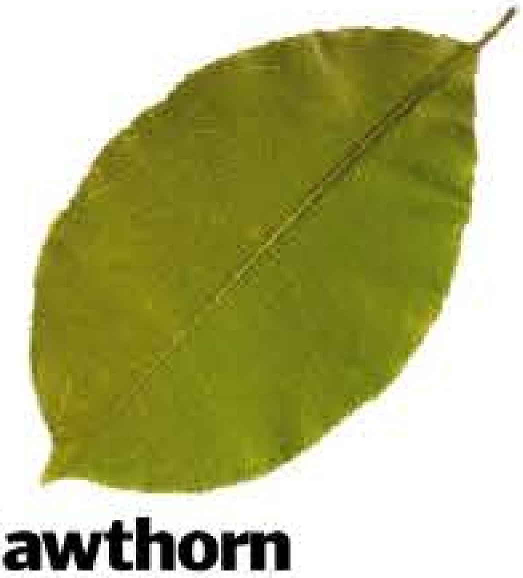
Horse chestnut

Each horse chestnut leaf is narrow at its base but broadens out towards the tip. All the leaves have a central vein that is quite prominent, along with a serrated margin.



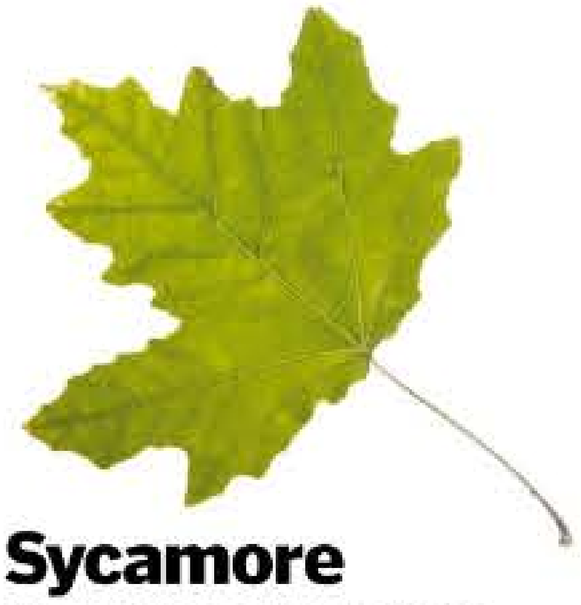
Elm

Elm leaves are characterised by their asymmetrical base and the way they taper to a sudden point at the top. They also have a jagged, saw-toothed edge and a rough, hairy surface.



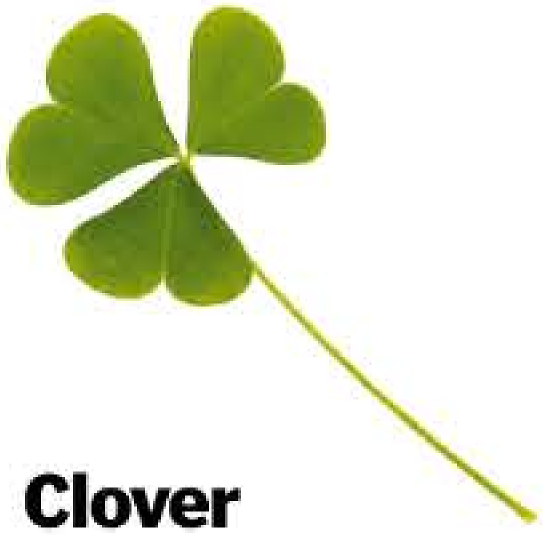
Hawthorn

Hawthorn leaves have a simple structure and tend to have a similar sized breadth and width. Many hawthorn hedges were planted during the Tudor period to mark farmland boundaries.



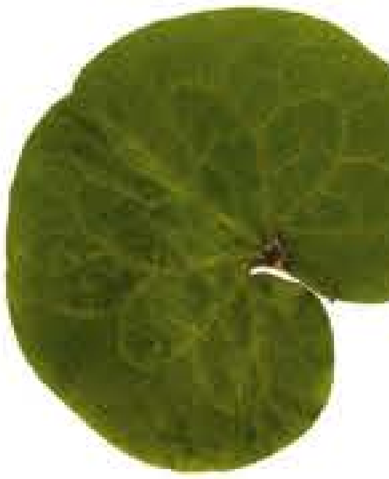
Sycamore

Sycamore leaves always have five distinctive lobes, along with five veins radiating from the base into the lobes. The leaf edge is quite ragged, with multiple rounded teeth all the way around it.



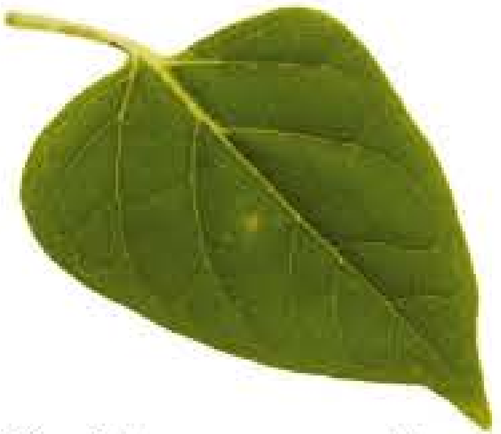
Clover

The clover leaf is typically trifoliate (has three leaflets) but the current world record is an incredible 56 leaflets! One in ten thousand have four leaflets instead of three, which many consider to be lucky.



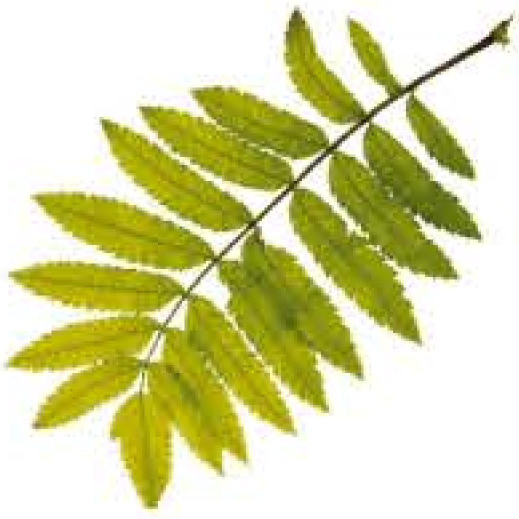
Water lily

Water lilies are famous for their round, waxy-coated leaves which sit on top of long stalks. The leaves protrude out of their freshwater habitat and float on the surface.



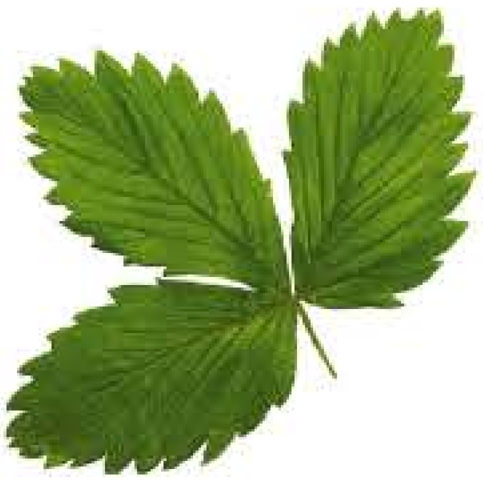
Cottonwood

Cottonwood leaves have an unusual triangular shape. Their petiole (which attaches each leaf blade to the stem) is a very important feature; it is flattened sideways to enable the leaf to move in a certain way in windy conditions.



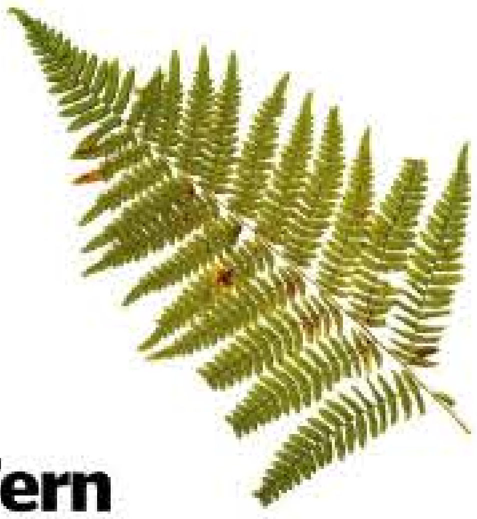
Rowan

The rowan tree (mountain ash), has compound leaves with up to 21-paired leaflets. Each has a serrated edge with small teeth and grey hairs underneath.



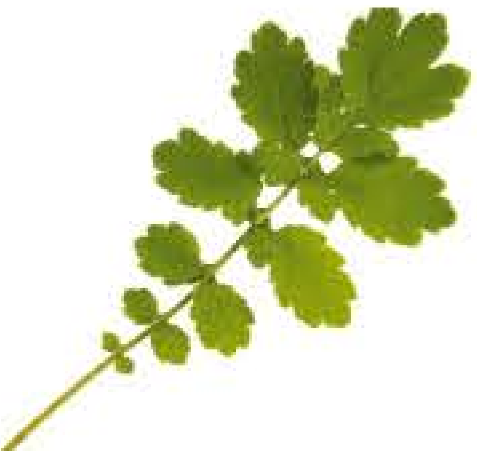
Strawberry

Strawberry plant leaves typically have three lobes and are dark green in colour. The leaf edge is jagged and curves upwards as the leaf unfurls, before flattening as they grow.



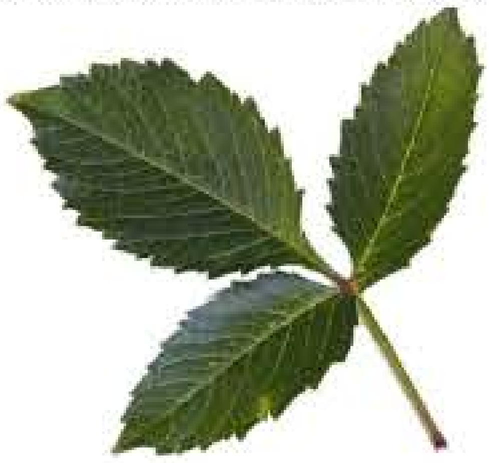
Fern

Fern branches are known as fronds which consist of a stalk with leaf-like growths sprouting from it. These leafy growths have a feathery structure and are commonly known as pinnae.



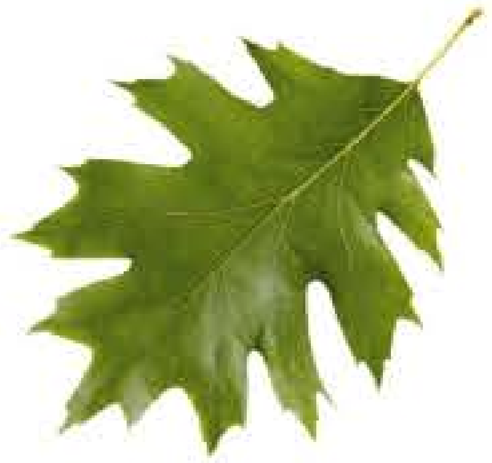
Celandine

The leaves of the greater celandine are heavily lobed and are a grey-green colour. Celandine leaf is used to form a herbal supplement to treat digestive disorders.



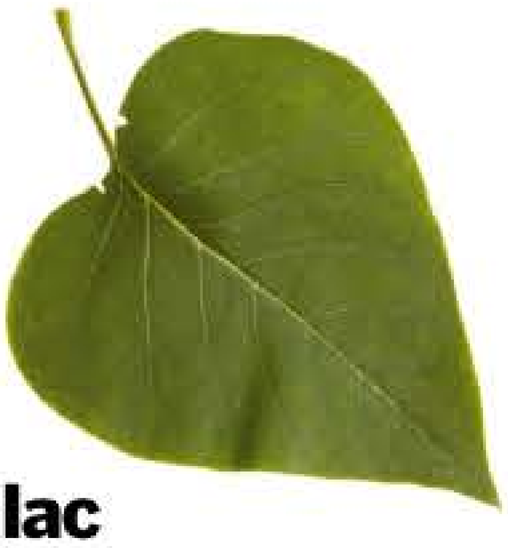
Bramble

Each bramble branch will have between five and seven leaflets growing from it, all of which have a particularly jagged edge. An army of sharp thorns grow on each stem, providing protection.



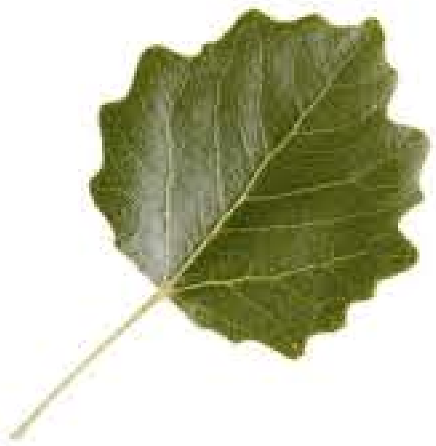
Red oak

Red oak leaves differ to those of white oaks in their lobe shape – red oaks have pointed lobes rather than round ones. Most red oaks have large leaves that are at least ten centimetres (four inches) in size.



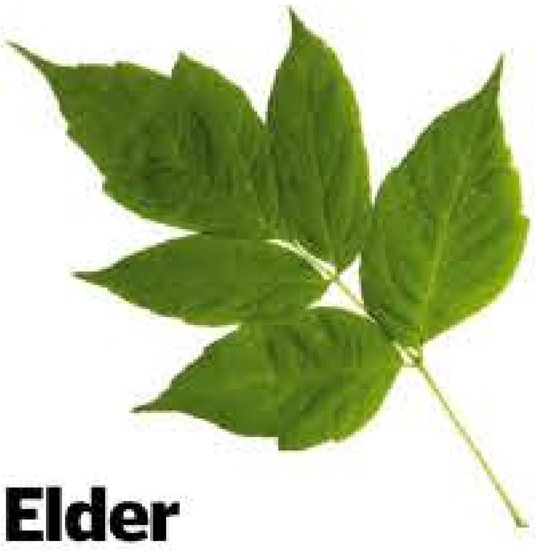
Lilac

Lilac tree leaves are characterised by their tear-drop shape which is rounded near the stem with a long 'drip tip' at the other end. They are dark green, and grow up to almost 13 centimetres (five inches) in length.



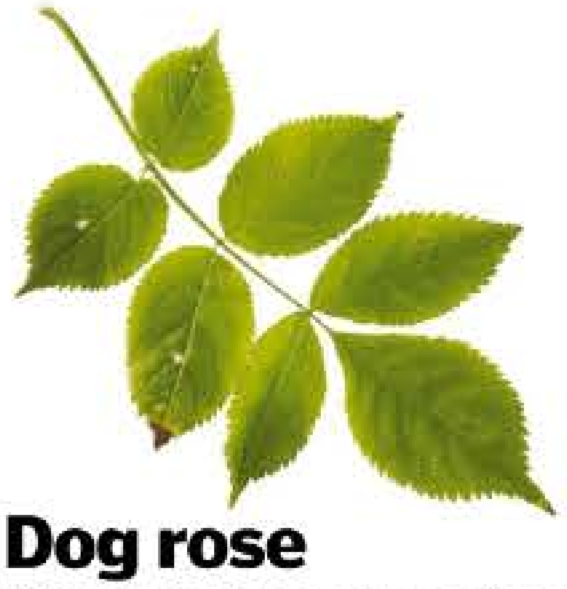
White poplar

White poplar leaves typically have a number of irregular lobes, however, those nearest the branch tips have three to five deep lobes. All leaves have a green upper surface and thick hair on the underside.



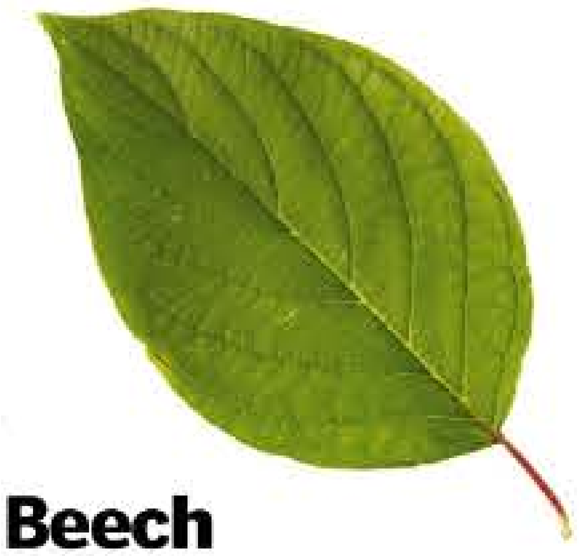
Elder

Each leaf is longer than it is wide, with a sharply toothed edge and small hairs on the underside. The leaves usually feature between five and seven leaflets in an opposite arrangement.



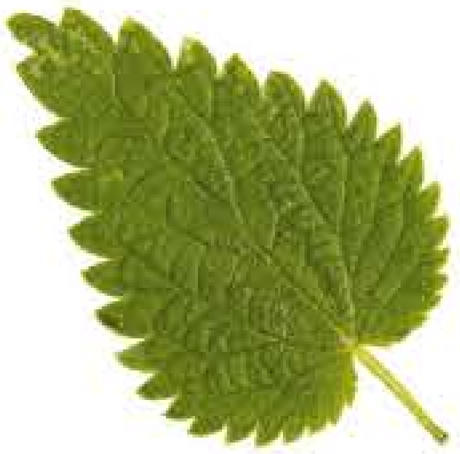
Dog rose

Between five and seven dog rose leaves form in compound pairs along each branch. These leaves are usually hairless and dark green in colour, with a slightly lighter underside.



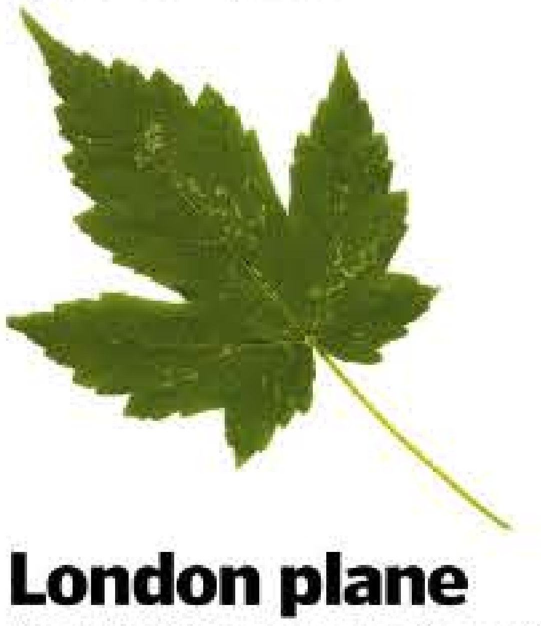
Beech

Beech leaves have a simple structure and appear alternately along the branches. When they first form, the leaves are light green and have small hairs. Once they mature, they darken and lose the small hairs.



Stinging nettle

The stinging nettle plant has fine toothed, tapered leaves, which can grow to 15 centimetres (5.9 inches) in length. These almost heart-shaped leaves can be eaten when cooked and work well as a spinach substitute.



London plane

Similar in style to the leaves of a maple or sycamore, leaves of the London plane are lobed and veined, with a darker top surface. Before they fall in the autumn, they turn a distinctive yellow or orange colour.

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Poisonous plants

They may look harmless, but some species of flora can be fatal

> *"It takes four castor seeds to kill a human, but 80 to kill a duck"*

There are lots of delicious and nutritious plants growing in nature, but there are also some that you should definitely keep off your plate. Even the most tasty-looking berries or succulent leaves can contain deadly poisons, while other plants are even harmful just to touch. It is thought that these poisonous plants evolved to contain their lethal toxins as a form of self-defence, poisoning the animals and humans who dare to eat or touch them to stop them from coming back for more. However, some plants affect animals and humans in different ways. For example, it takes just four castor seeds to kill a human, but 80 to kill a duck.

To make matters even more confusing, it is sometimes the case that only part of the plant is poisonous. For example, the stalks of rhubarb plants are great in a crumble, but eating the leaves, which contain oxalic acid, can cause nausea and vomiting. In other cases, toxic plants can actually benefit your health, as it has been discovered that the poisonous taxane alkaloids found in Yew trees contain chemicals that can be used to stop cancer cells from forming. Don't go munching on its leaves though, as you'll be left feeling rather unwell.

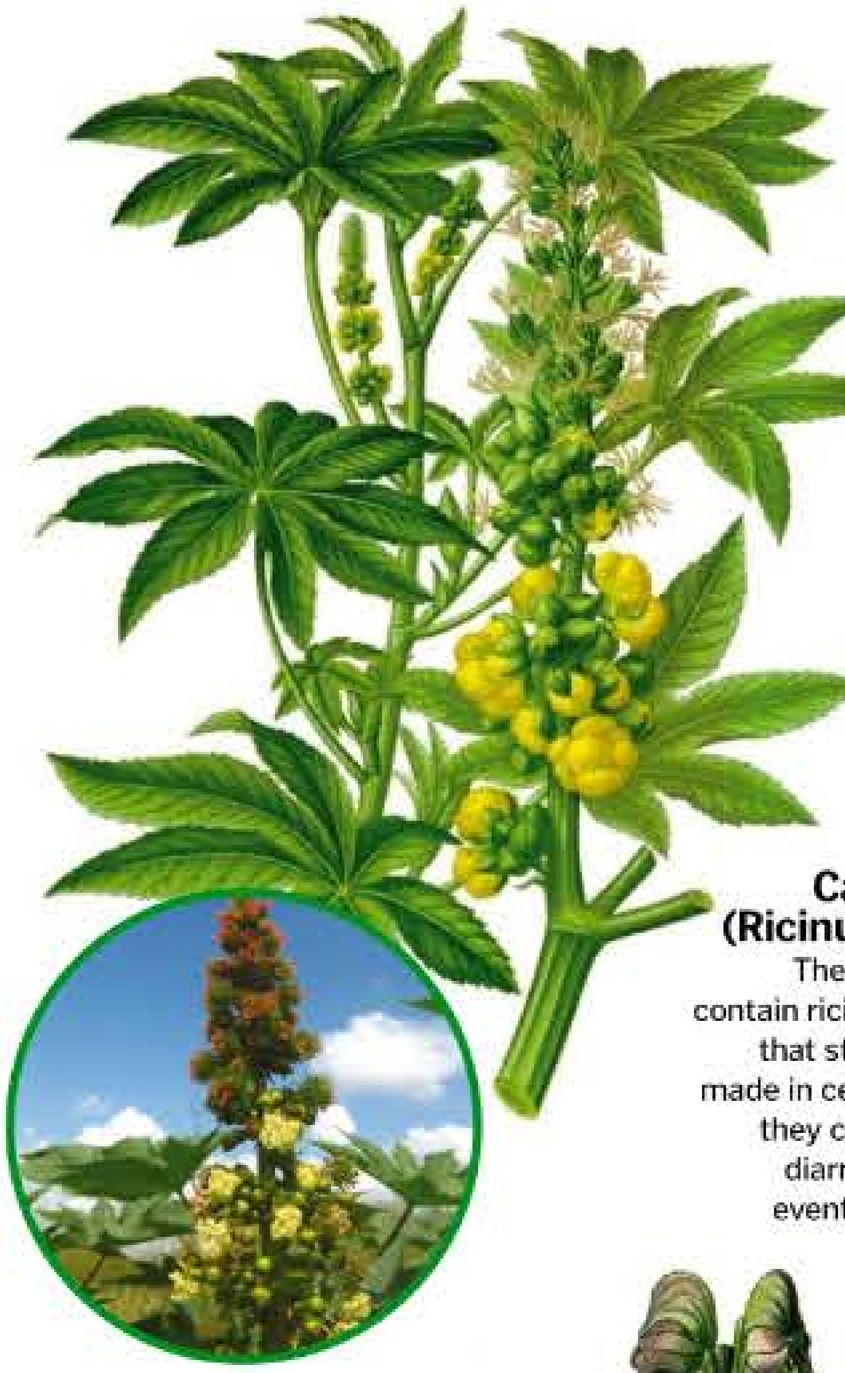
Poison hemlock (Conium maculatum)
All parts of poison hemlock contain toxic alkaloid compounds that, when ingested, can cause seizures, tachycardia and paralysis. This can lead to respiratory failure and ultimately death.

Foxglove (Digitalis)
Ingesting any part of this popular garden plant can result in severe poisoning. The cardiac glycoside toxins it contains can cause vomiting and diarrhoea, and in severe cases, visual distortion and heart problems.

Golden chain (Laburnum)
Laburnum seeds are carried in pods, which look like pea pods, but shouldn't be eaten. The plant contains the poisonous alkaloid cytisine, which can be deadly in large doses.

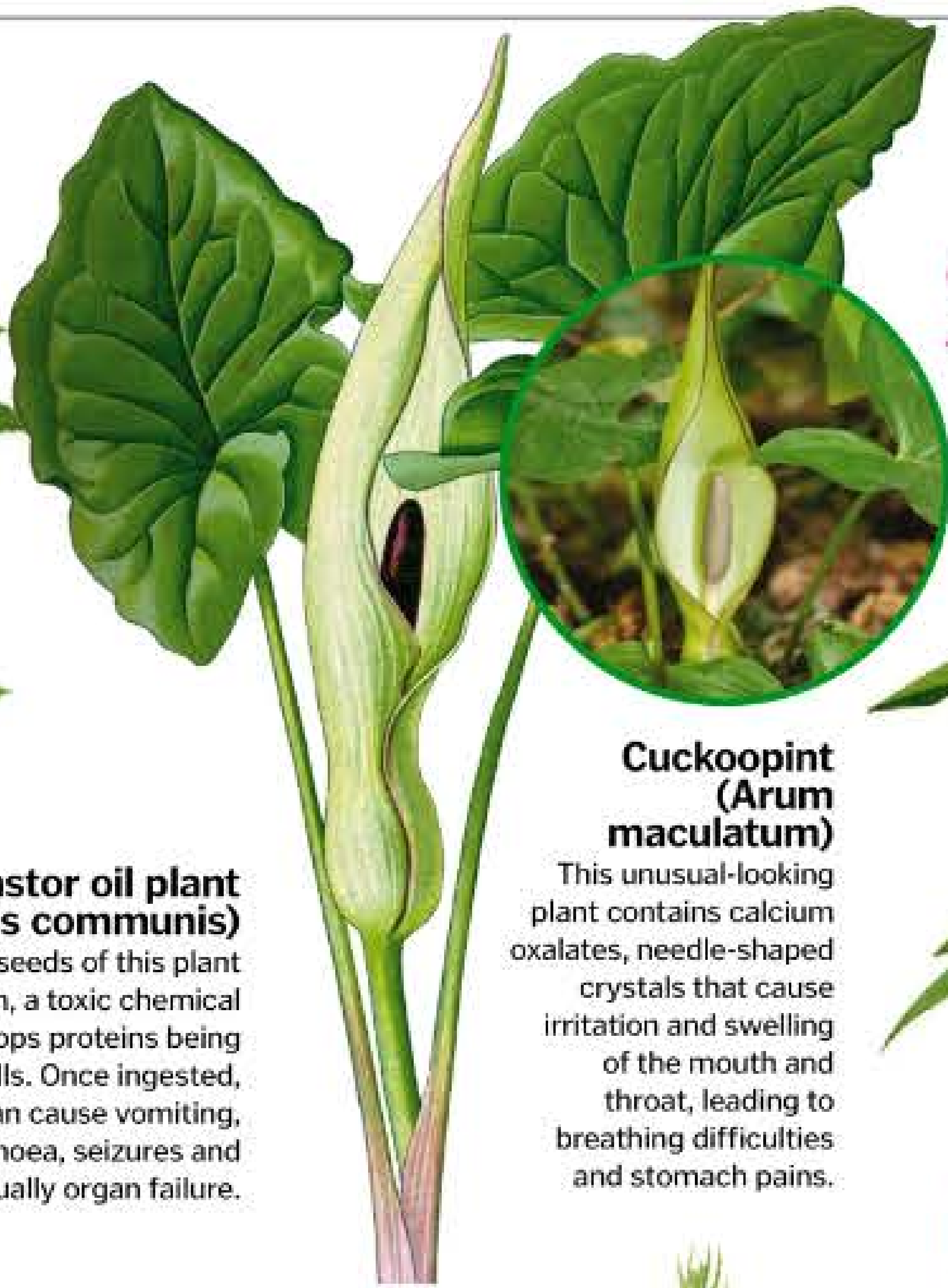
Poison ivy (Toxicodendron radicans)
Damaged poison ivy releases urushiol oil. If it makes contact with skin, it can cause a painful rash. Some people may have a more severe reaction, leading to swelling of the face and throat.

Yew (Taxus)
Highly poisonous taxane alkaloids can be found in all but the flesh of the berries of this evergreen tree. Once ingested, there are sometimes no symptoms until the victim collapses and dies.



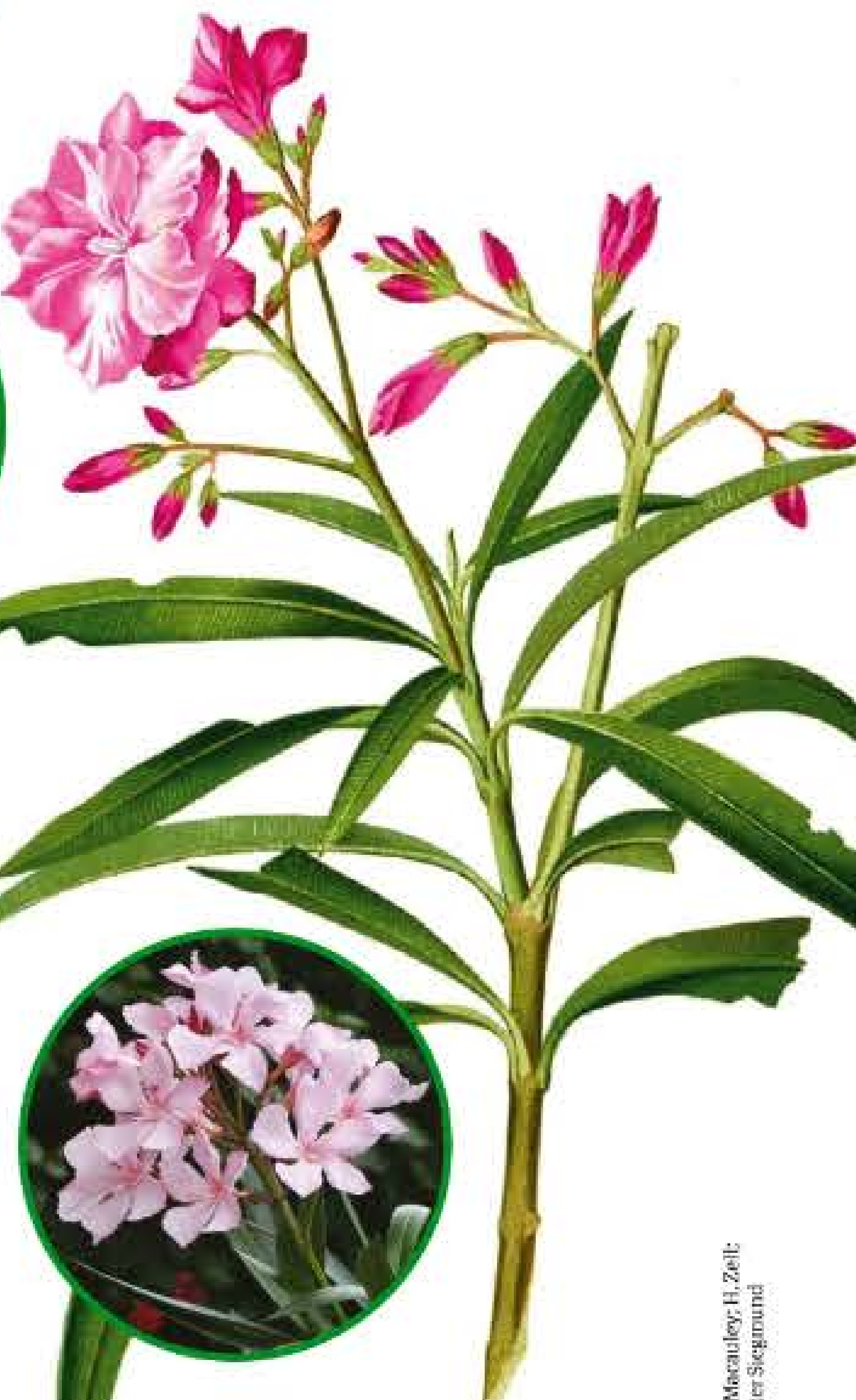
Castor oil plant (Ricinus communis)

The seeds of this plant contain ricin, a toxic chemical that stops proteins being made in cells. Once ingested, they can cause vomiting, diarrhoea, seizures and eventually organ failure.



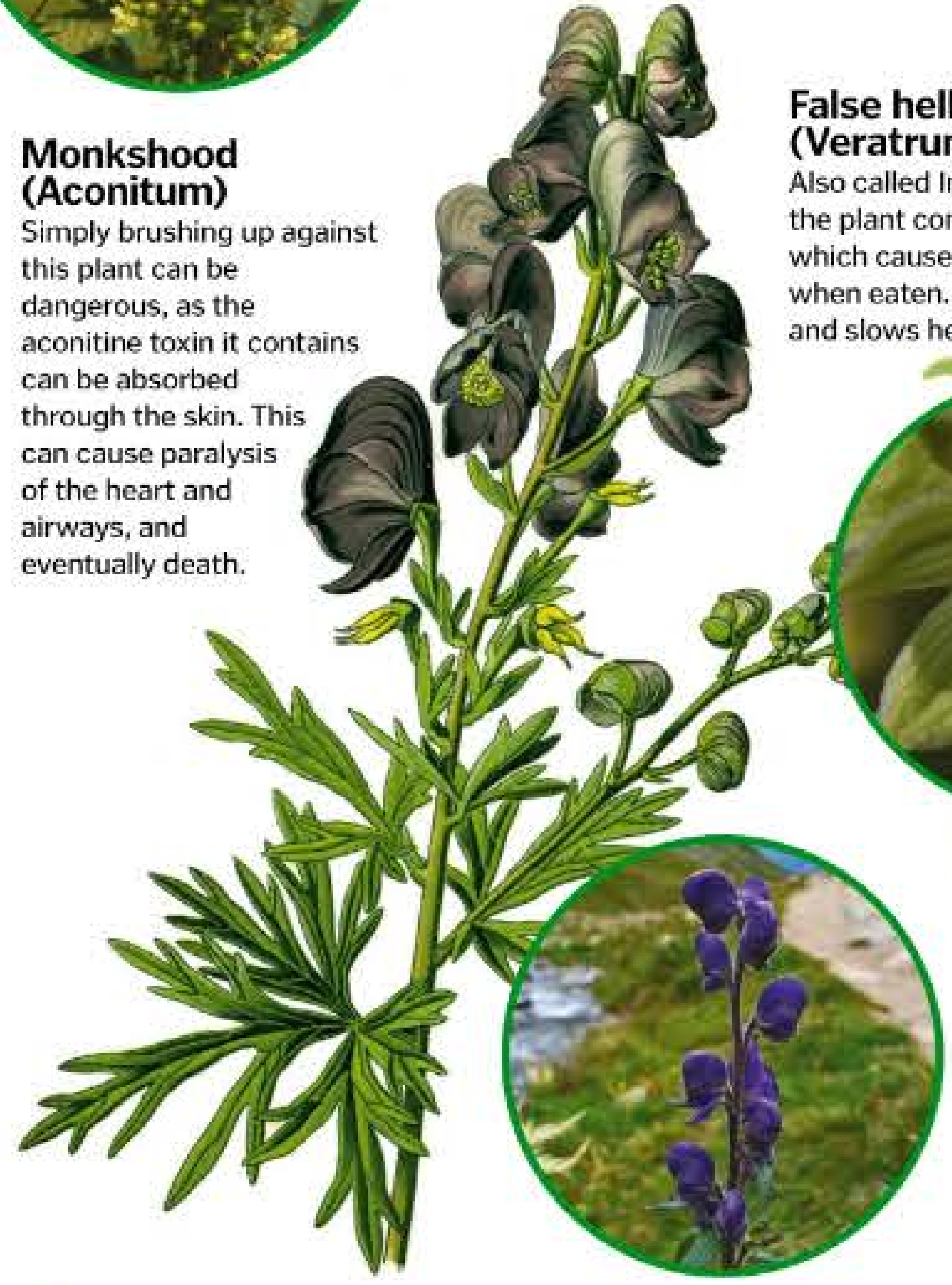
Cuckoopint (Arum maculatum)

This unusual-looking plant contains calcium oxalates, needle-shaped crystals that cause irritation and swelling of the mouth and throat, leading to breathing difficulties and stomach pains.



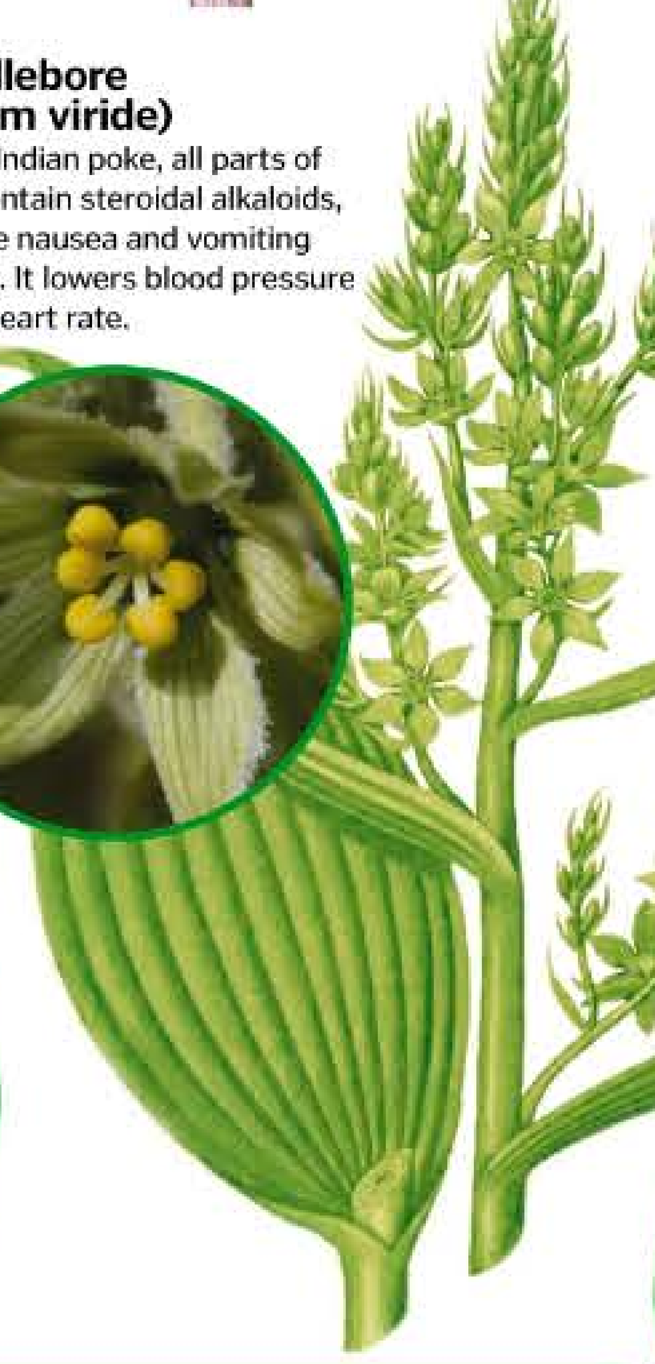
Oleander (Nerium oleander)

This ornamental, evergreen shrub contains cardiac glycoside, which can prove fatal if ingested directly or if food has come into contact with the plant, and it can irritate the skin when touched.



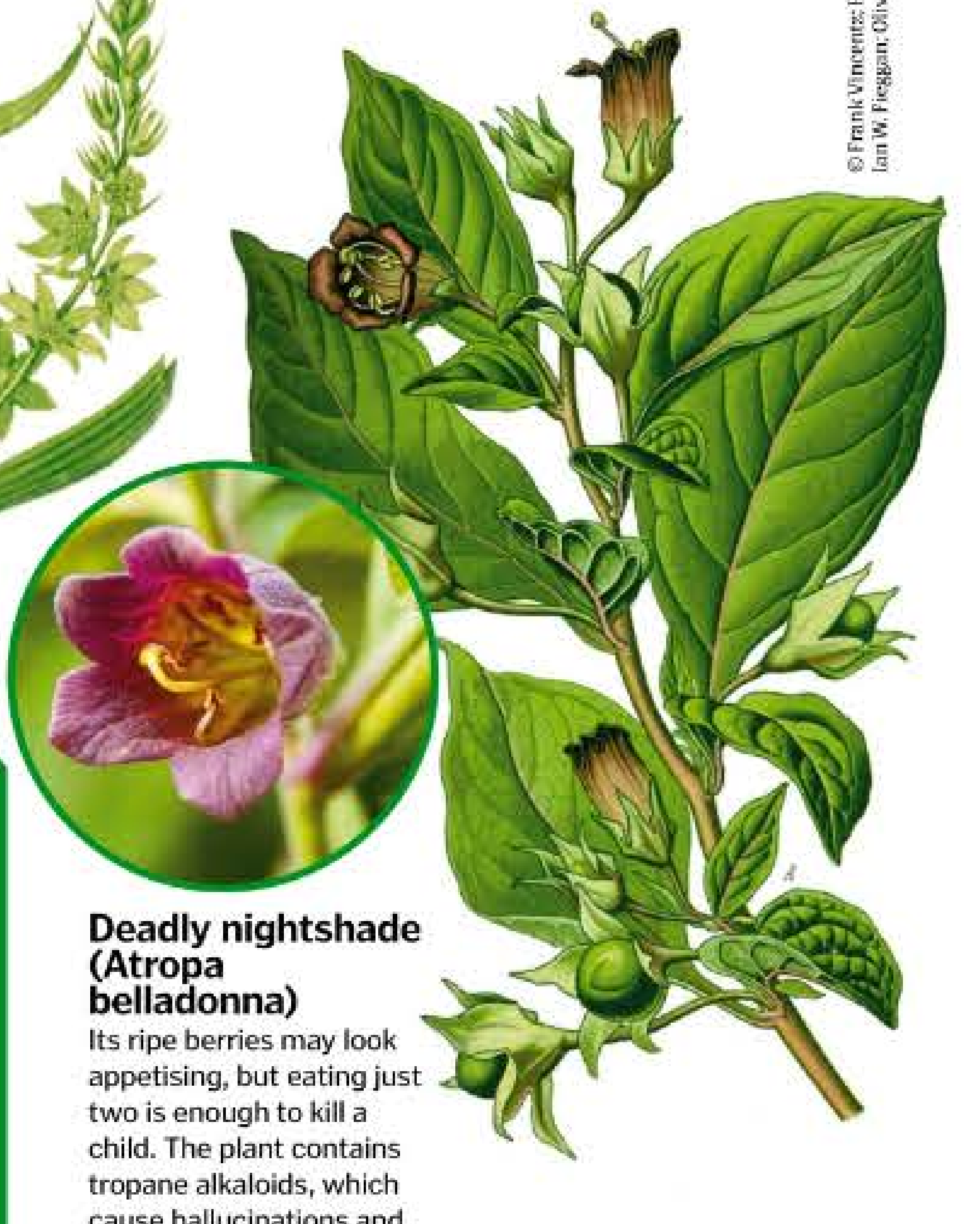
Monkshood (Aconitum)

Simply brushing up against this plant can be dangerous, as the aconitine toxin it contains can be absorbed through the skin. This can cause paralysis of the heart and airways, and eventually death.



False hellebore (Veratrum viride)

Also called Indian poke, all parts of the plant contain steroidal alkaloids, which cause nausea and vomiting when eaten. It lowers blood pressure and slows heart rate.



Deadly nightshade (Atropa belladonna)

Its ripe berries may look appetising, but eating just two is enough to kill a child. The plant contains tropane alkaloids, which cause hallucinations and attack the nervous system.

When gardening, wear gloves to prevent dangerous plants from coming into contact with your skin

How to avoid poisonous plants

When outdoors, it is always best to be cautious around unfamiliar plants, and avoid touching or eating them unless you know they are safe. If you do have a reaction or become unwell after touching or ingesting a plant, visit a doctor straight away and take a piece of the plant with you. This will help them to identify it and determine the best cause of treatment. For many poisonous plants, there is no antidote available, but if caught early enough, the symptoms can usually be treated to avoid serious health problems or death.

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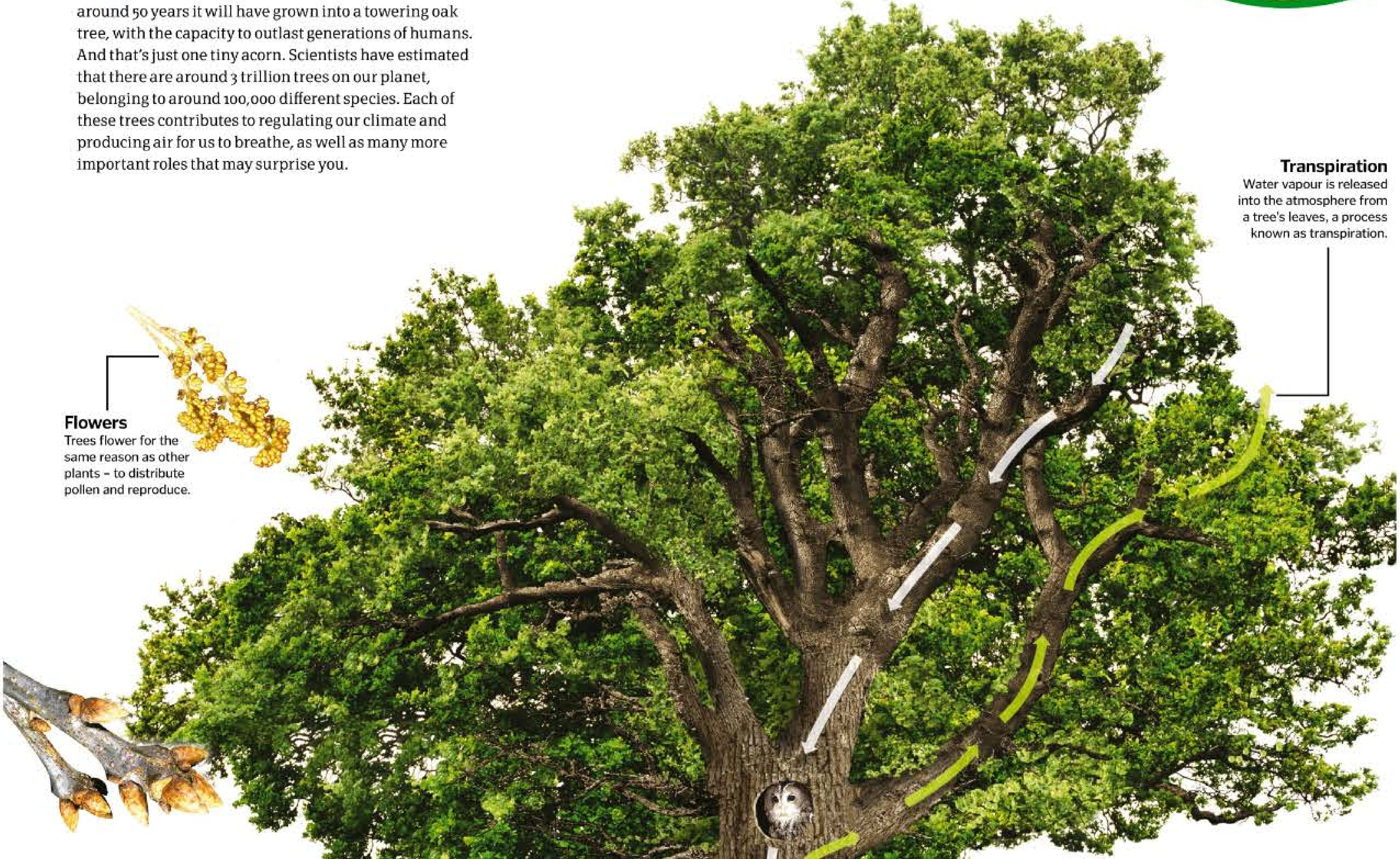
The life of trees

From seed to forest giant, discover how trees grow and why you can't live without them

When you look at a tiny acorn on the forest floor, it's difficult to imagine just how much potential that little seed contains. If it germinates, after around 50 years it will have grown into a towering oak tree, with the capacity to outlast generations of humans. And that's just one tiny acorn. Scientists have estimated that there are around 3 trillion trees on our planet, belonging to around 100,000 different species. Each of these trees contributes to regulating our climate and producing air for us to breathe, as well as many more important roles that may surprise you.

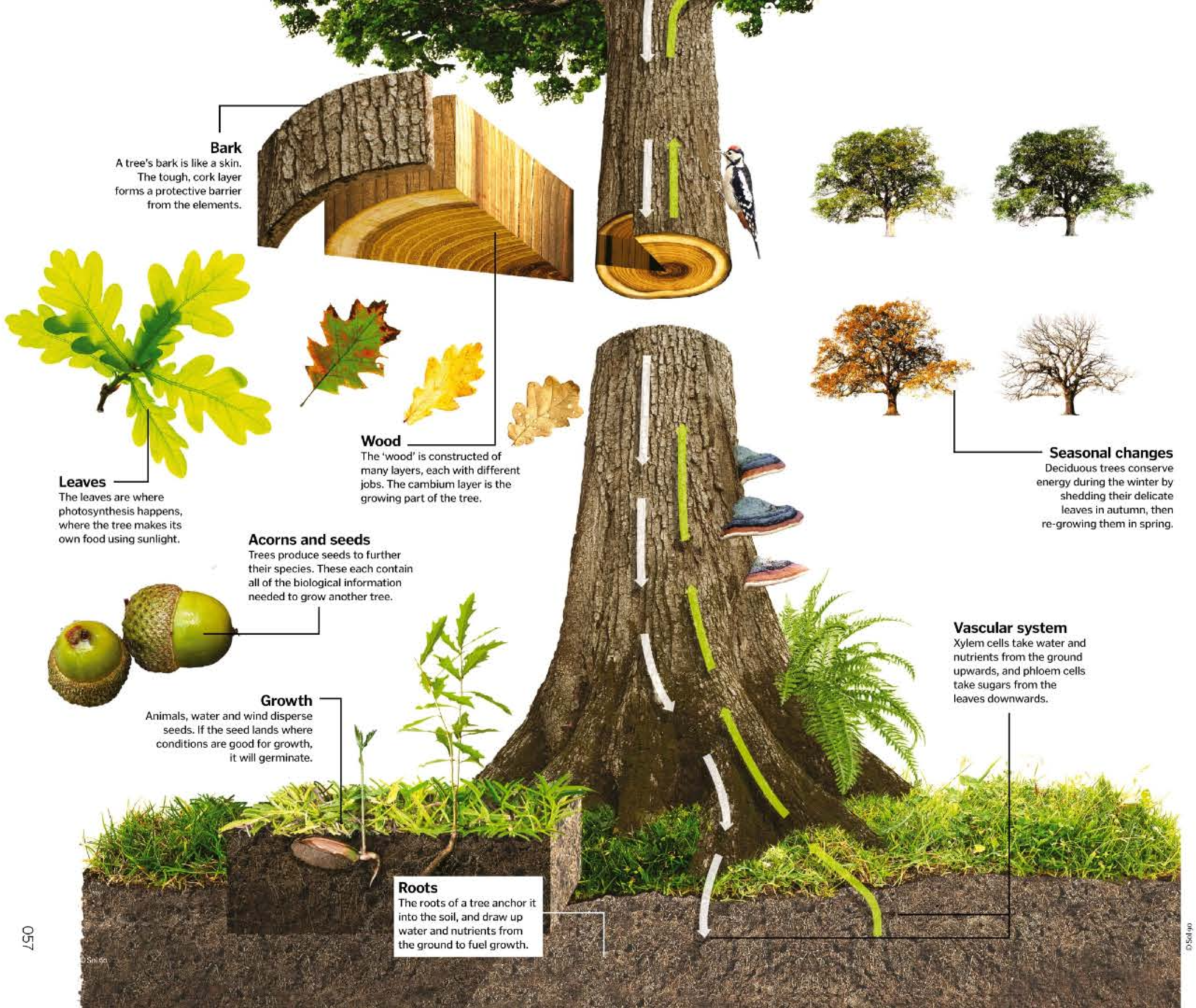
There are around 600 species of oak tree, found across the Northern Hemisphere



Transpiration
Water vapour is released into the atmosphere from a tree's leaves, a process known as transpiration.

Flowers
Trees flower for the same reason as other plants – to distribute pollen and reproduce.

DID YOU KNOW? *'Pando' is a colony of quaking aspen trees in Utah, which has a single root mass and is around 80,000 years old*



Bark
A tree's bark is like a skin. The tough, cork layer forms a protective barrier from the elements.

Leaves
The leaves are where photosynthesis happens, where the tree makes its own food using sunlight.

Wood
The 'wood' is constructed of many layers, each with different jobs. The cambium layer is the growing part of the tree.

Acorns and seeds
Trees produce seeds to further their species. These each contain all of the biological information needed to grow another tree.

Growth
Animals, water and wind disperse seeds. If the seed lands where conditions are good for growth, it will germinate.

Roots
The roots of a tree anchor it into the soil, and draw up water and nutrients from the ground to fuel growth.

Vascular system
Xylem cells take water and nutrients from the ground upwards, and phloem cells take sugars from the leaves downwards.

Seasonal changes
Deciduous trees conserve energy during the winter by shedding their delicate leaves in autumn, then re-growing them in spring.

© Sol90

© Sol90

Woodland wildlife

Forests are home to more wildlife than any other landscape

From leaves to bark and everything in between, every inch of woodland is useful to one critter or another. Large populations of trees create many varied habitats, from pine forests to wet woodlands, each with different ecological properties and a unique wildlife population.

In summer, when a tree's leaves are in full bloom, the dense foliage of the woodland canopy absorbs the Sun's energy, providing shade and regulating the woodland's climate. Similarly, in the winter months, the dense network of leaves and branches are an effective barrier against pouring rain and howling wind, sheltering the animals within.

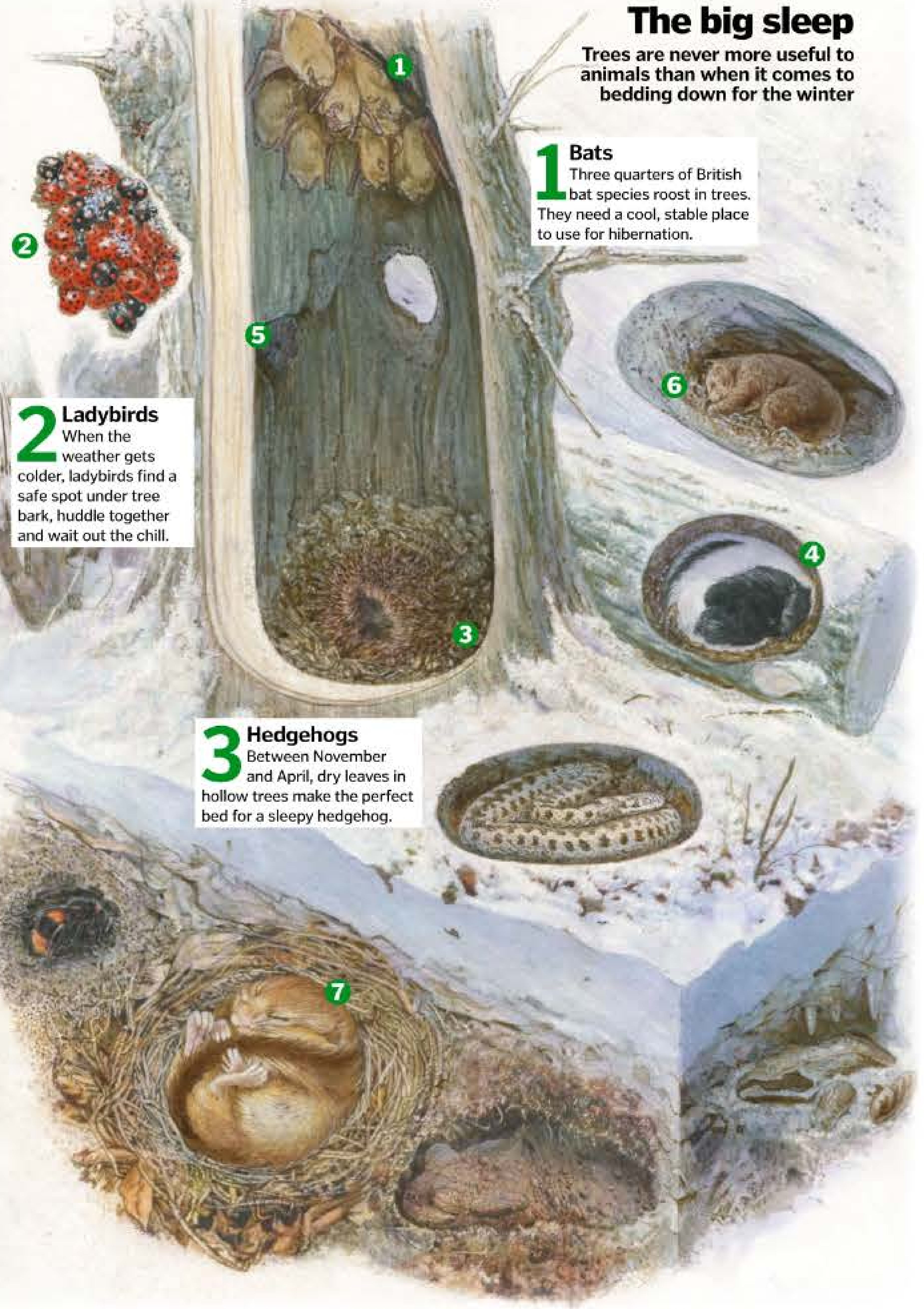
Green leaves, buds, fruit and bark provide food for many animals, such as squirrels, deer and birds. A tree's branches make handy perches for feasting upon, or a perfect vantage point to lie in wait for prey. Refuge is also found high up in the branches, safe from the clutches of forest-floor predators.

Lines of trees can also connect different ecosystems together, providing green corridors for animals to cross between different habitats, maintaining the flow of food and nutrients throughout the countryside.

The tree's structure itself provides plenty of nooks and crannies for wildlife to hide in. Birds build nests on branches or hollow out the bark, insects live on the underside of leaves, bats and dormice seek out tree cavities for refuge and burrowing critters weave throughout the roots. Even when a tree dies it's useful; leaf litter creates a rich mix of nutrients on the forest floor for scavengers, and dead wood can support countless plants, insects and fungal species.

The big sleep

Trees are never more useful to animals than when it comes to bedding down for the winter



1 Bats
Three quarters of British bat species roost in trees. They need a cool, stable place to use for hibernation.

2 Ladybirds
When the weather gets colder, ladybirds find a safe spot under tree bark, huddle together and wait out the chill.

3 Hedgehogs
Between November and April, dry leaves in hollow trees make the perfect bed for a sleepy hedgehog.

4 Badgers
Badgers live in tunnel networks known as setts. Tree roots make these underground dens more stable.

5 Moths
Depending on the time of year, moths and caterpillars can use branches for hibernating in large groups.

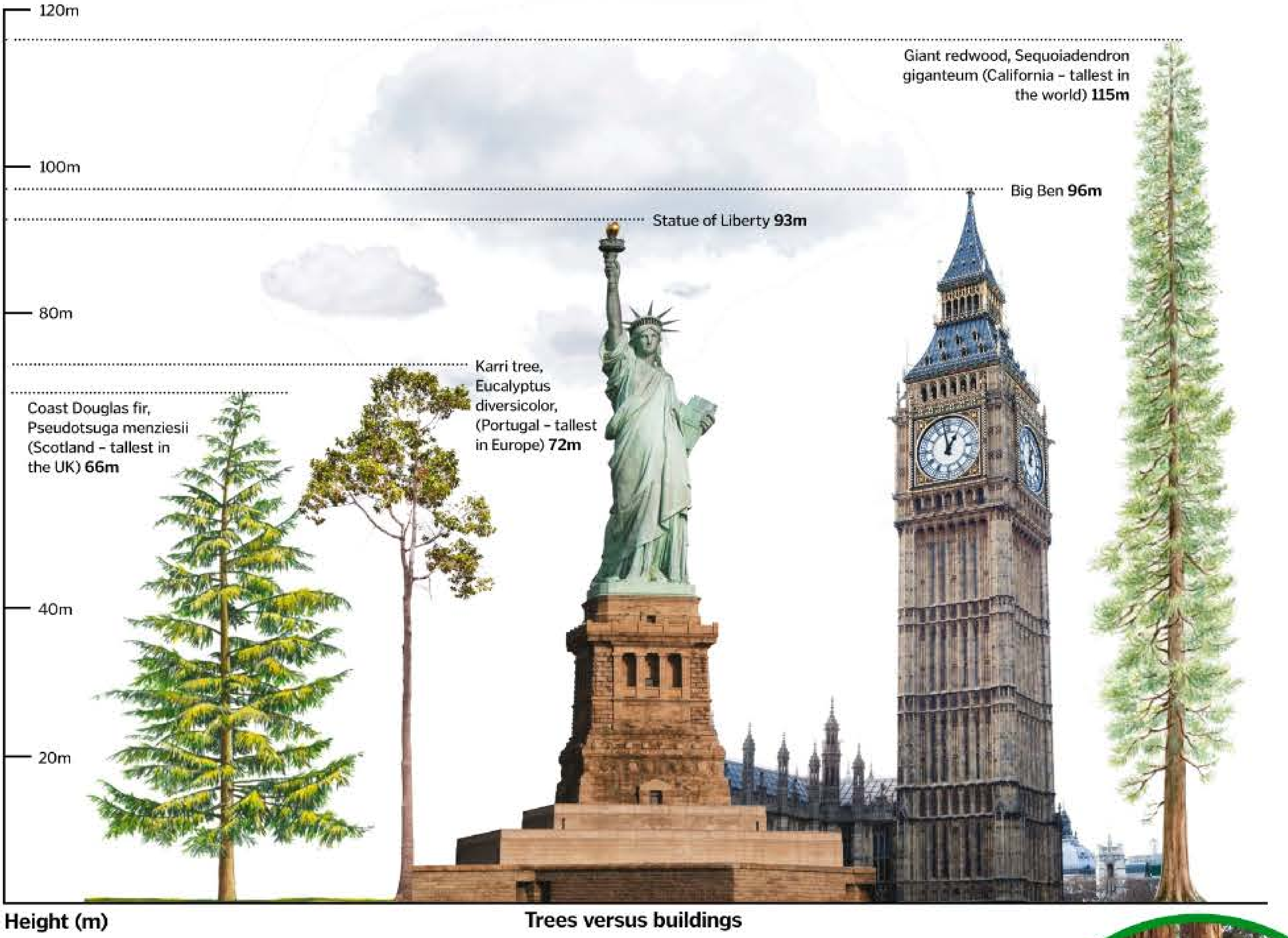
6 Bears
These great beasts will collect leaves, branches and brushes of trees to create a warm bed to curl up in.

7 Dormice
Found living in deciduous woodland, dormice make cosy nests to keep out of the winter chill.

Tawny owls make their homes in hollows of trees, sheltering from the elements

DID YOU KNOW? *It is estimated that all of the world's forests combined absorb 8.8 billion tons of carbon dioxide per year*

The world's tallest trees



The importance of trees

The forest does far more for us humans than provide beautiful walks and firewood

Giant redwoods thrive in the warm, humid climate of northern California

Trees are the lungs of our planet. As a key part of the carbon cycle, when trees photosynthesise to make their own food, they take in carbon dioxide and convert it to release oxygen, storing the rest of the carbon that gets decomposed into the soil when the tree dies. When a whole forest does this, the intake of CO_2 is huge. With rising CO_2 levels in our atmosphere being an important factor in climate change, the work of trees becomes all the more prominent. It's estimated that our planet's trees absorb up to 40 per cent of the carbon dioxide created by humans each year.

When the trees are cut down, this carbon storage is removed, but so is the tree's ability to stabilise the earth and take up water. Deforestation creates a landscape where water flows uninterrupted, taking valuable, nutrient-laden surface soil with it. This leaves land barren and infertile – a disaster for agriculture and those who depend on farming for their livelihood. Flash floods wreak havoc and threaten human life, and have been directly linked to the removal of trees across the world. Downstream, the soil that has been removed by floods is deposited as the flow peters out, and can clog up dams and create further issues.

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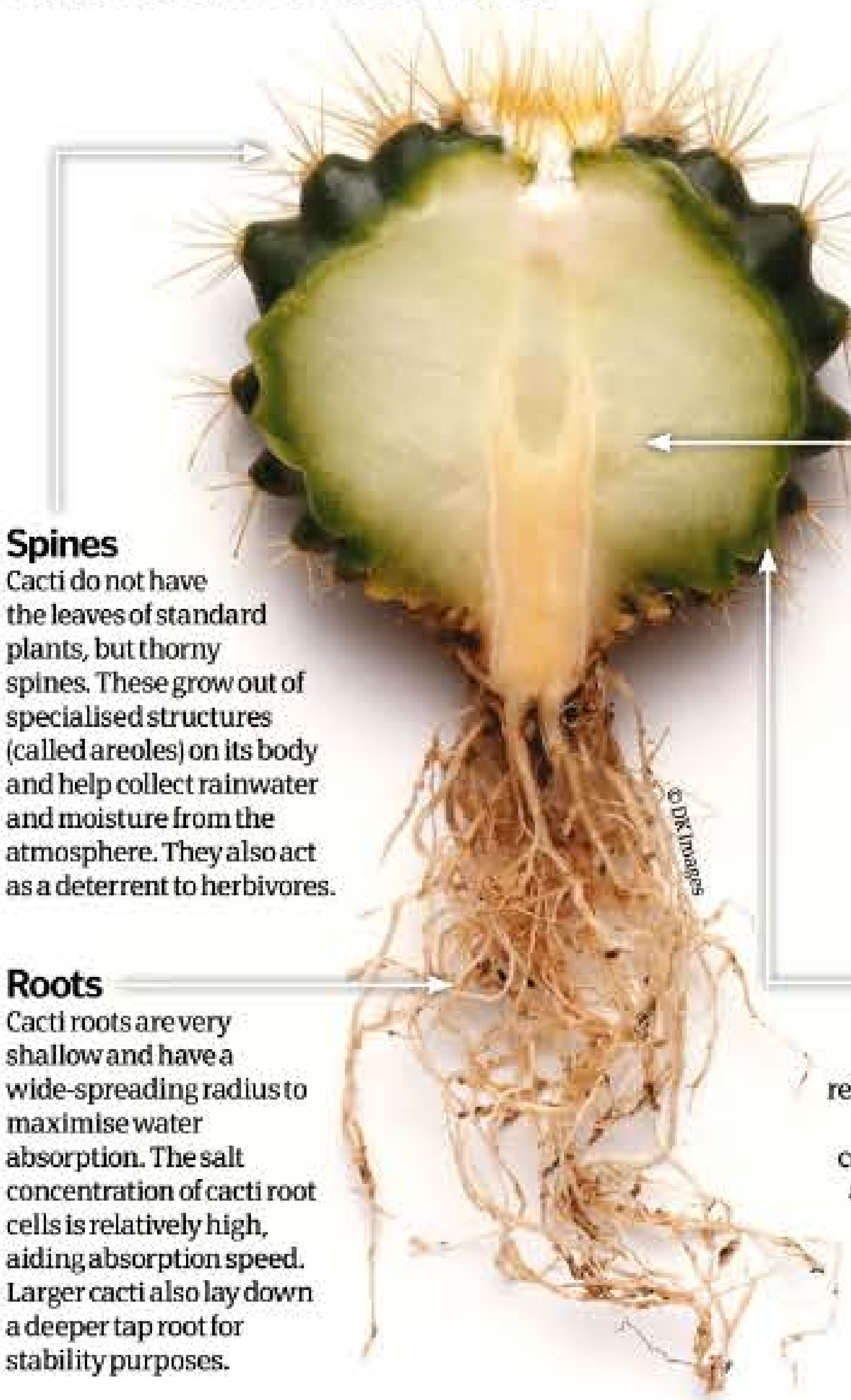
How do cacti live?

Take a closer look at the materials and mechanisms cacti use to survive in the world's harshest environments



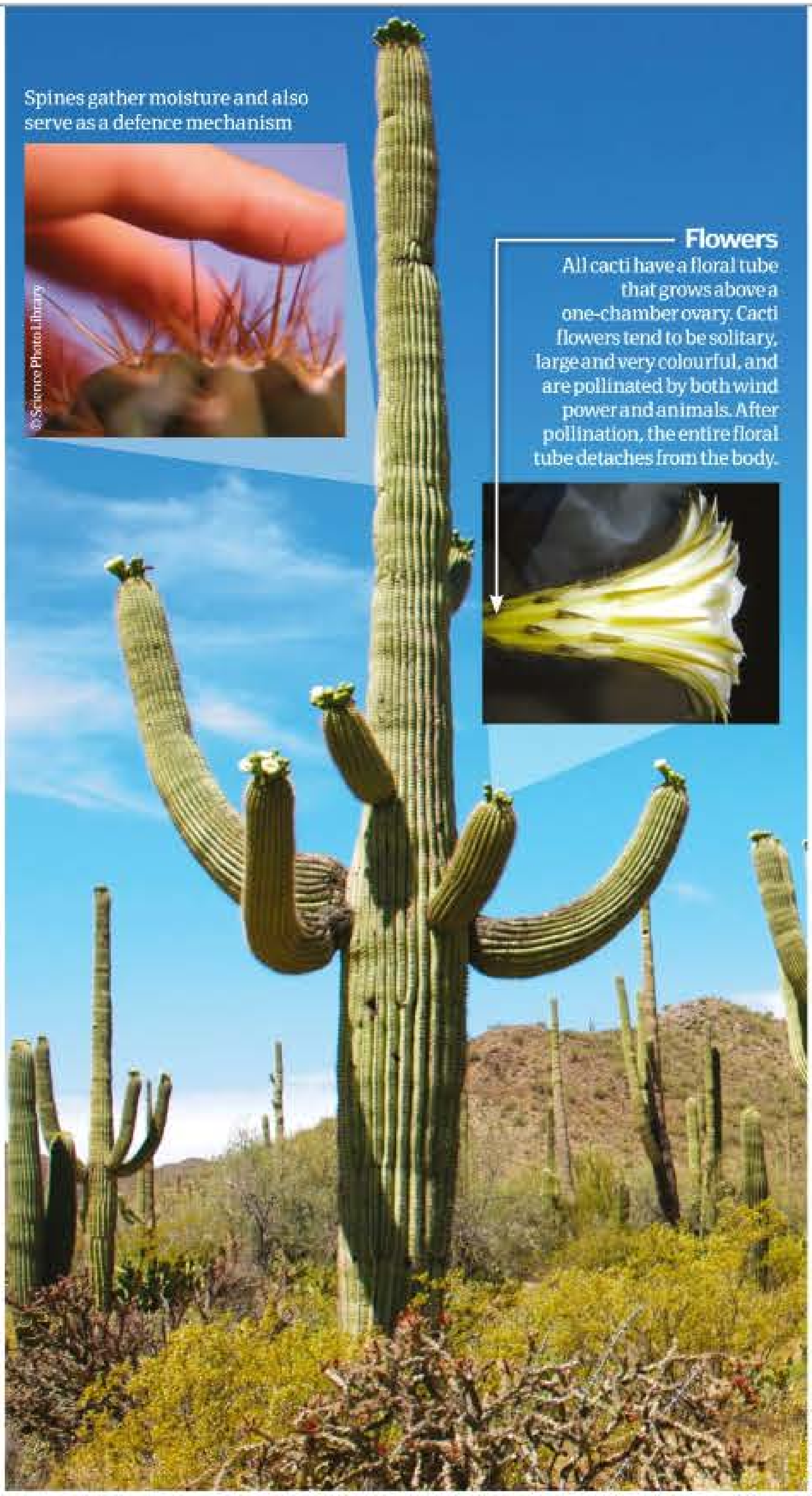
Spines
Cacti do not have the leaves of standard plants, but thorny spines. These grow out of specialised structures (called areoles) on its body and help collect rainwater and moisture from the atmosphere. They also act as a deterrent to herbivores.

Tissue
The main bulk of the cacti's body comes in the form of a water-retentive tissue, often in the optimal shape for storage (a sphere or cylinder). At the centre of the body tissue lies the stem, the main organ for food manufacturing and storage.

Roots
Cacti roots are very shallow and have a wide-spreading radius to maximise water absorption. The salt concentration of cacti root cells is relatively high, aiding absorption speed. Larger cacti also lay down a deeper tap root for stability purposes.

Skin
The skin of a cactus is specially adapted to reduce the harsh effects of constant sunlight. It is constructed from a tough and thick fibrous sheath and coated with a thin layer of wax. These factors, in conjunction with its optimal shape, aid water retention.

© DK Images



Spines gather moisture and also serve as a defence mechanism

© Science Photo Library

Flowers
All cacti have a floral tube that grows above a one-chamber ovary. Cacti flowers tend to be solitary, large and very colourful, and are pollinated by both wind power and animals. After pollination, the entire floral tube detaches from the body.

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Cacti are hardy, flowering plants in the caryophyllales order that have evolved to survive in some of the Earth's driest and most barren landscapes. This unceasing survival is achieved through the specialised tailoring of two main principles: form and function.

First, all cacti have developed optimal forms for retention of internal water supplies (spheres and cylinders), combining the highest possible volume for storage with the lowest possible surface area for loss. This allows cacti to store vast quantities of water for elongated periods – for example, the species Carnegiea gigantea can absorb 3,000 litres in a mere ten days. This ability directly correlates to the typical weather patterns of Earth's barren, dry environments, where cacti are predominantly found, with little water being deposited for months on end, only for a short monsoon to follow in the rainy season. This optimal structural form also grants much-needed shadow for lower areas of the plant, shielding them from the harsh sunlight.

Second, cacti have evolved unique mechanisms and adapted traditional plant functions to grow and thrive. Foremost among these changes are the cacti's spines, elongated spiky structures that grow out from its central body though areoles (cushion-like nodes). These act as a replacement for leaves, which would quickly die if exposed to high levels of sunlight and high temperatures. The spines have a membranous structure and can absorb moisture directly from the atmosphere (especially important in foggy conditions) and also from deposited rainwater, capturing and absorbing droplets throughout the body's spiny matrix. In addition, due to the lack of leaves, cacti have evolved so as to undertake photosynthesis directly within their large, woody stems, generating energy and processing stored water safely away from the intense sunlight.

Finally, cacti have modified their root structures to remain standing stable in the brittle, parched earth. Cacti roots are very shallow compared with other succulents and are spread out in a wide radius just below the Earth's crust. This, in partnership with an intense salt concentration, allows cacti to maximise their access to and absorbability speed of ground water, sucking it up before it evaporates or trickles down deeper into the Earth. For stability, many cacti also extend a main 'tap root' further into the Earth, in order to act as an anchor against high winds and interference from animals.

DID YOU KNOW? *The first commercially cloned animal was a cat, Little Nicky. Born in 2004, it cost its owner £30,000 ($50,000)*

How are plants cloned?

Find out how we make identical copies of plants and what benefits this offers

The process of cloning plants has been used in agriculture for centuries, as communities split roots and took cuttings to efficiently create multiple plants.

Taking a cutting from near the top of a plant, placing it in moist soil and covering it will enable a new offspring to grow with the same genetic code as the parent from which it was taken. This method of cloning is very easy to do and is common among casual gardeners and industrial farmers alike. However, in more recent years the cloning of plants has made its way into the laboratory.

Responsible for that shift is German physiologist Gottlieb Haberlandt who was the first to isolate a plant cell and then try to grow an exact replica of the parent. His attempt ultimately failed, but the experiment showed enough promise to convince others to follow in his footsteps. The likes of Hannig in 1904 and Kolte and Robbins in 1922 ran successful experiments in which they also cultured plant tissue to create new versions.

The main benefit of cloning flora is that growers are able to guarantee disease-free plants by cultivating cells from strong and healthy ones, leading to higher and more reliable crop yields. By taking cuttings from proven strains, a farmer can be sure his next generation of crops is equally successful.

Back inside the lab, the development of cloning through cultivating plant tissue allows for many plant species to even be adapted and improved upon. However this genetic modification remains a controversial topic to many people, as some experts argue we can't predict what the consequences of this human interference will be.

Plant cloning can be as basic as snipping off a stem from a begonia or as complex as growing a tomato plant in a solution of inorganic salts and yeast extract, but nevertheless the process by which you can create two plants out of one remains a triumph of natural science.

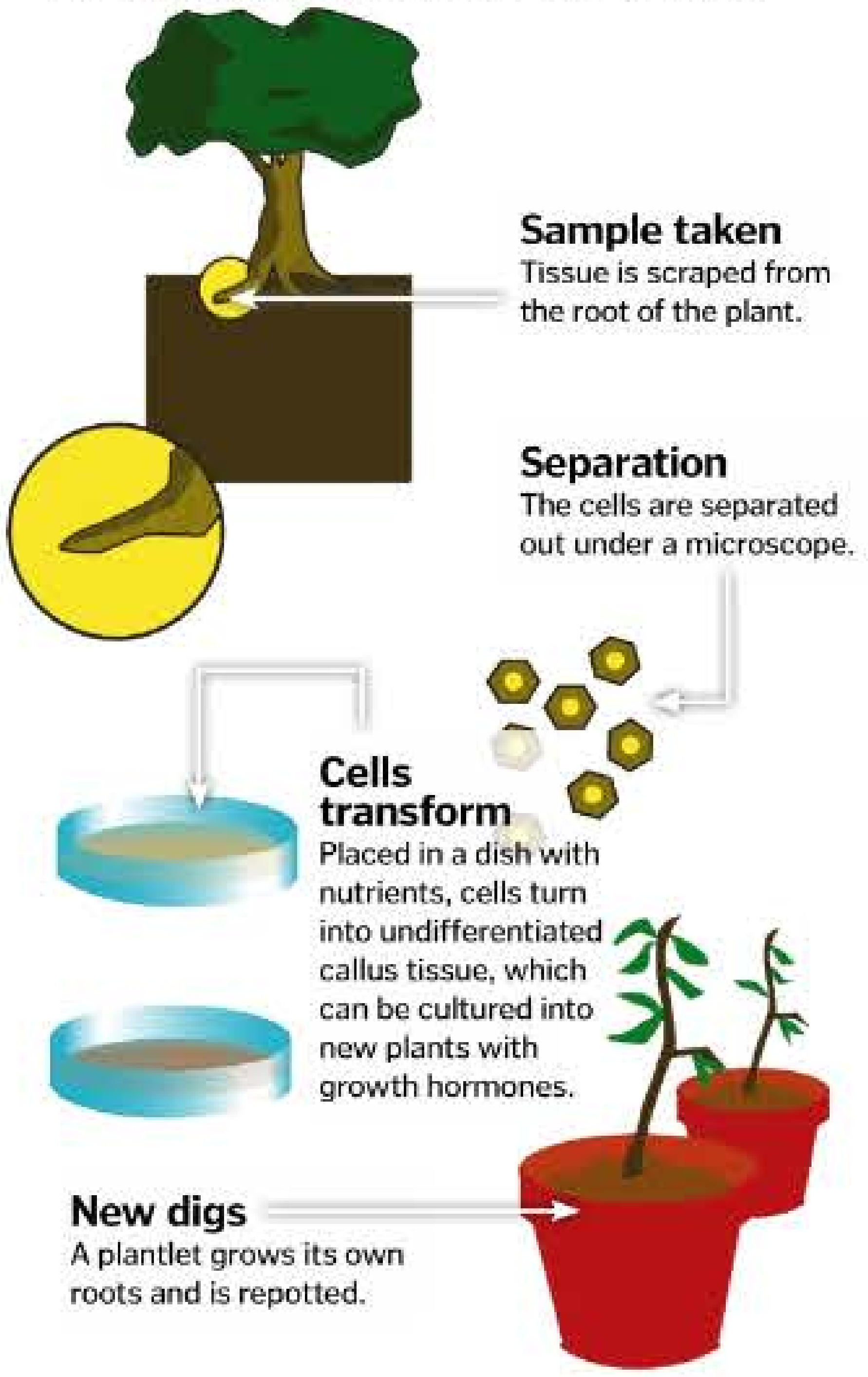
Dolly lived to be almost seven years old

What about animals?

Most of us are aware of Dolly the sheep, the first animal cloned from an adult cell, but artificial cloning dates back to the late-19th century. Hans Dreisch created two sea urchins by separating two urchin embryo cells from which two offspring grew, proving that DNA is not lost through separation. The next big development came in 1952 when a frog embryo was cloned by inserting the nucleus from a tadpole's embryo cell into an unfertilised frog egg cell. But the creation of Dolly in 1996, cloned using a mammary cell from an adult sheep, led to hopes that one day we might be cloned as well. There's still a while until a human can be replicated, but Dolly represented a huge leap forward in terms of cloning possibilities.

Plant duplication guide

Discover how plants can be cloned in the lab through the process of cell separation



Sample taken
Tissue is scraped from the root of the plant.
Separation
The cells are separated out under a microscope.
Cells transform
Placed in a dish with nutrients, cells turn into undifferentiated callus tissue, which can be cultured into new plants with growth hormones.
New digs
A plantlet grows its own roots and is repotted.

Laboratory plant cloning is used for scientific research and to develop stronger strains

© Alamy; SPL

How do plants grow towards light?

A hormone makes sure the plant has enough sunlight to survive

Sunflowers follow the Sun's rays throughout each day by rotating their leaves and flowers

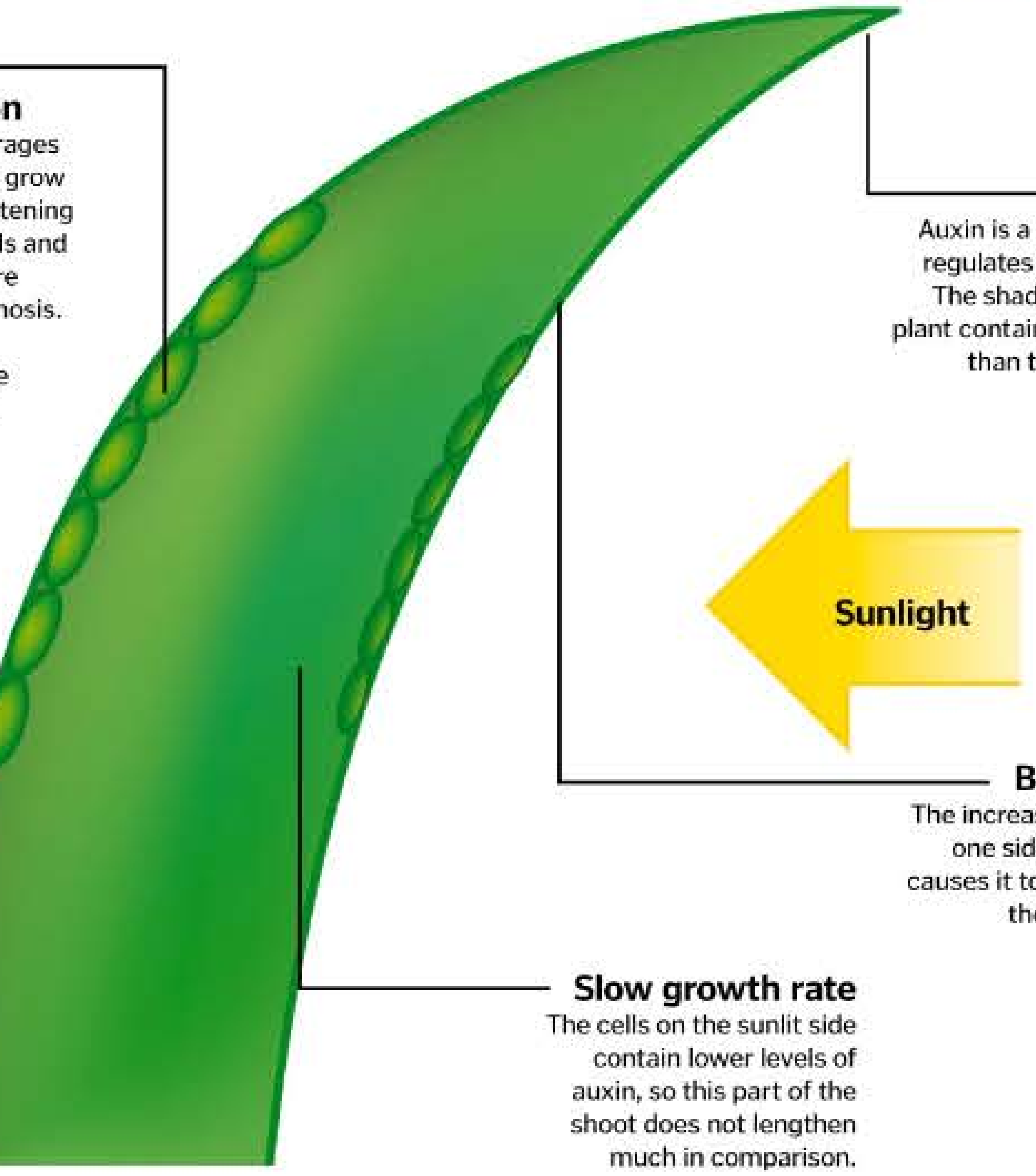
Plants depend on a process called photosynthesis to make their own food. This process converts water from the soil and carbon dioxide in the air into oxygen and glucose (sugar). Sunlight is crucial for this chemical change and without it, green plants are unable to survive.

Plant cells contain a protein called phototropin, which is activated when it absorbs the blue wavelength of light. This leads to an uneven distribution of the hormone auxin (which regulates growth) in the stem. The exact mechanisms behind this process are not fully understood, but one theory is that sunlight destroys or inhibits auxin so the hormone levels on the Sun-facing side reduce. Another theory is that auxin molecules are able to move from cell to cell across the stem, away from the area where light was detected by the phototropins. Auxin causes cells to enlarge, so the shaded side of the stem – which contains higher levels of the hormone – elongates, forcing the plant to bend towards the light as a result.

Sunflowers take their quest for sunlight to the extreme. These plants follow the Sun throughout the day, physically rotating their leaves and flowers to make the most of the available light. At night they then unwind, returning to their starting position ready for sunrise. No one knows why the flowers follow the Sun as well as the leaves, although it's thought the extra heat may help to grow more seeds.

Phototropism

With the help of the hormone auxin, plants can get as much light as possible



Cell elongation
Auxin encourages plant cells to grow in size by softening their cell walls and taking in more water by osmosis. This in turn elongates the shaded side.

Auxin
Auxin is a hormone that regulates plant growth. The shaded side of the plant contains more auxin than the sunlit side.

Bent shape
The increased growth of one side of the shoot causes it to bend toward the light source.

Slow growth rate
The cells on the sunlit side contain lower levels of auxin, so this part of the shoot does not lengthen much in comparison.

Killer plants

Not satisfied with making food through photosynthesis, these five carnivorous plants capture, kill and eat living prey

Drosera
There are over 100 species of drosera, which are commonly known as 'sundews' as they appear to be constantly covered in dew. These tiny droplets are actually sticky enzymes that trap and start to digest prey as soon as it lands on the plants' leaves.

Venus flytrap
When an insect or arachnid steps on more than one of the tiny hairs of the plant's jaws, it triggers a violent reaction. The hinged mouth snaps down, trapping the prey inside the plant. Digestive enzymes are secreted and it can be several days until the plant re-opens.

Nepenthes
These plants lure insects, and sometimes even rats, into their cup-like pitchers with an attractive scent. Once trapped, the prey drowns in the liquid within the pitcher and is broken down by digestive juices, allowing the plant to absorb the vital nutrients it needs to survive.

Pinguicula
This plant catches prey using sticky leaves. The tacky substance is actually full of digestive enzymes, which break down the insects once they become trapped. When winter arrives, some species of pinguicula become quite dormant and cease their carnivorous activities.

Sarracenia
Like nepenthes, sarracenia is a pitcher plant. Insects are attracted to its colours and sweet scent. As they land at the edge of the pitcher, they often fall in, since the edge is very slippery. Once inside, there is no escape due to the smooth, steep sides of the pitcher.

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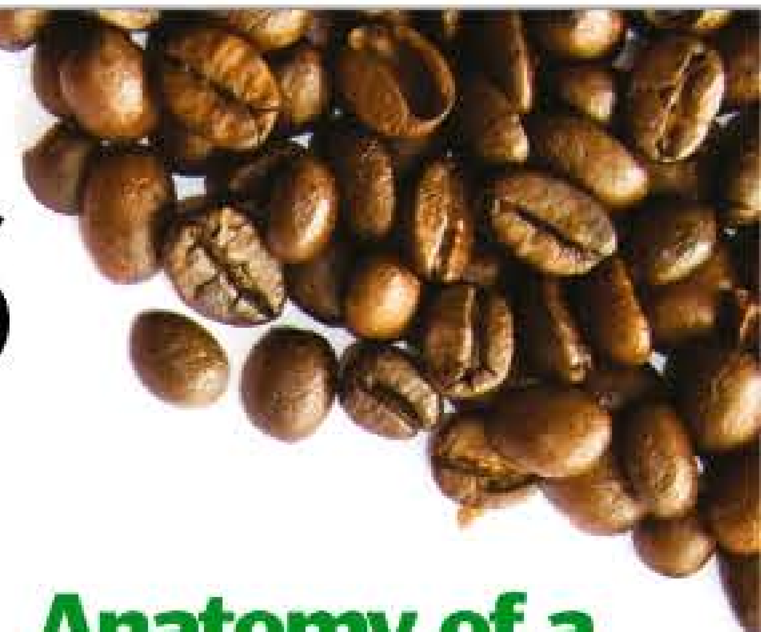
DID YOU KNOW? *Ancient Ethiopians are credited as first recognising the energising effect of the coffee plant*



Coffee plants

From seed to a steaming hot cup of tasty beverage, we explain how coffee is grown and cultivated

Coffee production starts with the plantation of a species of coffee plant, such as the arabica species. Plants are evenly spaced at a set distance to ensure optimal growing conditions (access to light, access to soil nutrients, space to expand). Roughly four years after planting, the coffee plant flowers. These flowers last just a couple of days, but signal the start of the plant's berry-growing process.

Roughly eight months after flowering, the plant's berries ripen. This is indicated by the change in shade, beginning a dark-green colour before changing through yellow to a dark-red. Once dark-red, the berries are then harvested by strip picking or selective picking. The former is an often mechanised technique where an entire crop is harvested at once, regardless of being fully ripe or not. By doing this, the producer can quickly and cheaply strip a plantation but at the expense of overall bean quality. The latter technique is more labour-intensive, where workers handpick only fully ripe berries over consecutive weeks. This method is slower and more costly, but allows a greater degree of accuracy and delivers a more consistent and quality crop.

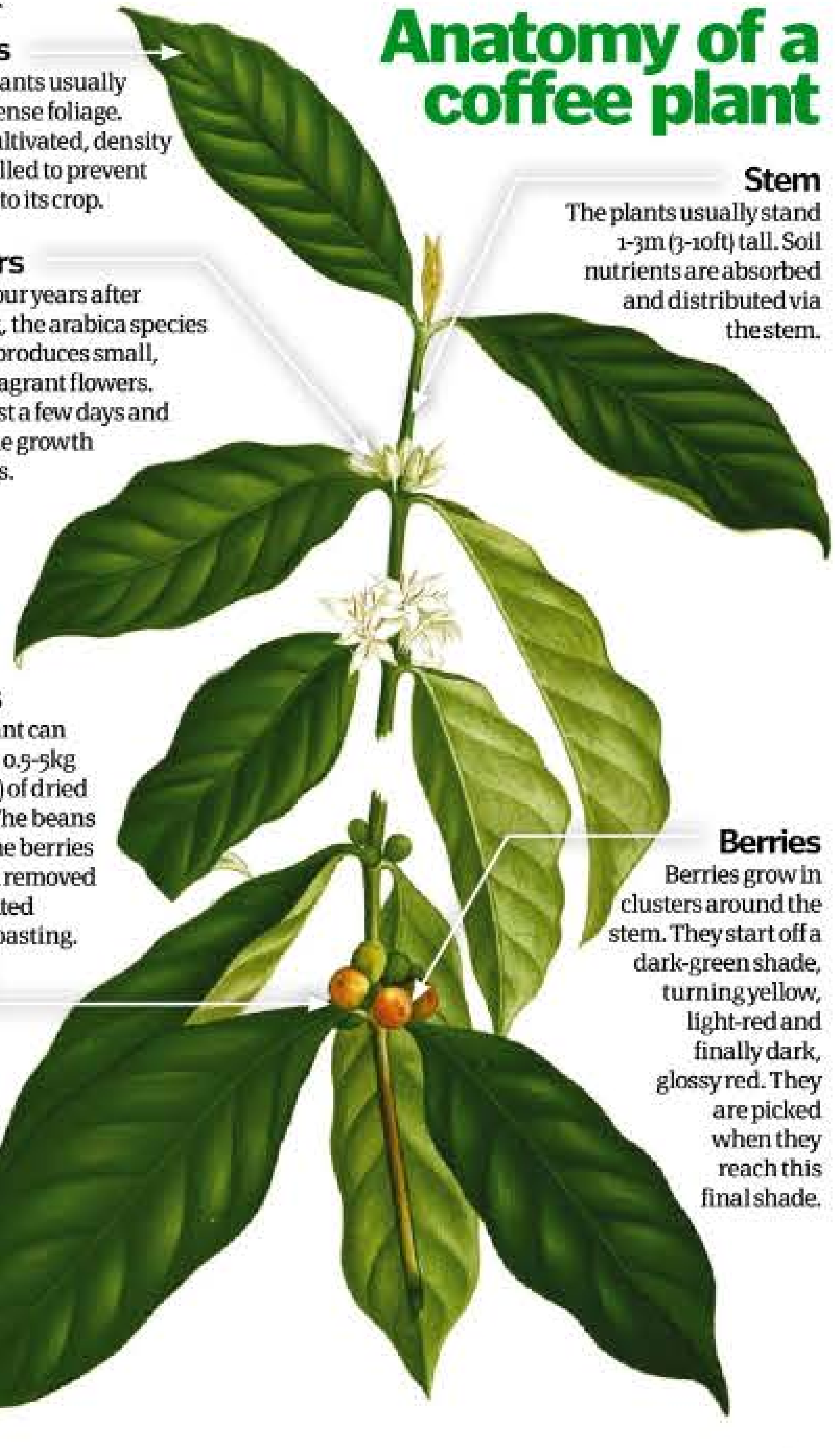
Once the berries have been harvested, the bean acquisition and milling process begins. Processing comes in two main forms, wet and dry. The dry method is the oldest and most predominant worldwide, accounting for 95 per cent of arabica coffee. This involves cleaning the berries whole of twigs, dirt and debris, before spreading them out on a large concrete or brick patio for drying in the sun. The berries are turned by hand every day, to prevent mildew and ensure an even dry. The drying process takes up to four weeks, and the dried berry is then sent to milling for hulling and polishing.

The wet method undertakes hulling first, with the beans removed from the berries before the drying process. This is undertaken by throwing the berries into large tanks of water, where they are forced through a mesh mechanically. The remainder of any pulp is removed through a fermentation process. As with the dry method, the beans are then spread out on a patio for drying.

Workers pick large quantities of coffee berries

The final stage is milling. This is a series of four processes to improve the texture, appearance, weight and overall quality. Beans that have been prepared the dry way are first sent for hulling to remove the remaining pulp and parchment skin. Next, the beans are sent for polishing. This is an optional process, in which the beans are mechanically buffed to improve their appearance and eliminate any chaff produced during preparation. Third, the beans are sent through a battery of machines that sort them by size and density (larger, heavier beans produce better flavour than smaller and lighter ones). Finally the beans are graded, a process of categorising beans on the basis of every aspect of their production.

Anatomy of a coffee plant



Leaves
Coffee plants usually have a dense foliage. When cultivated, density is controlled to prevent damage to its crop.

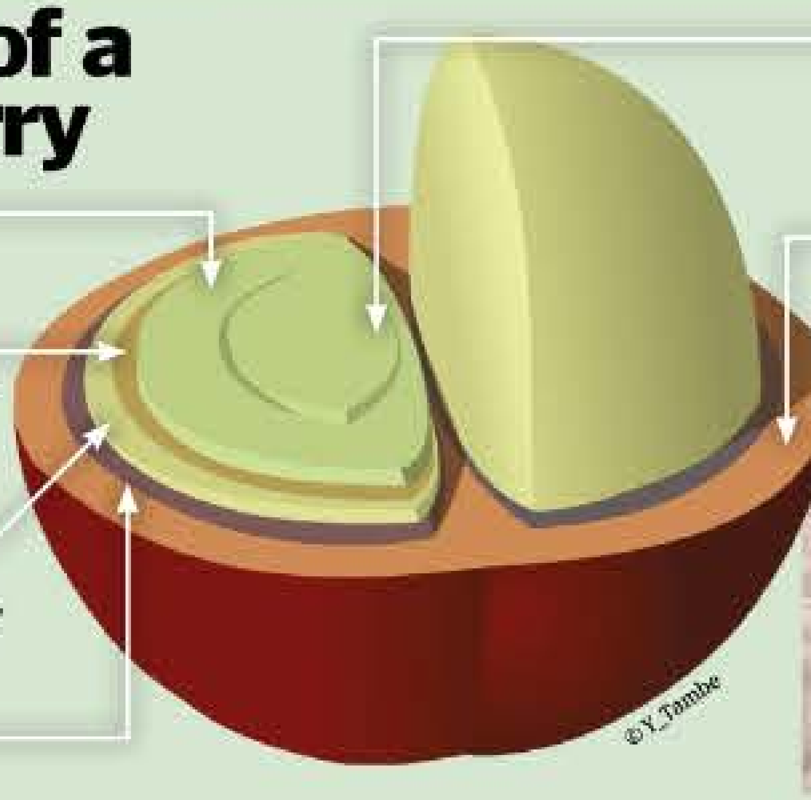
Flowers
Two to four years after planting, the arabica species of plant produces small, white, fragrant flowers. These last a few days and signal the growth of berries.

Beans
Each plant can produce 0.5-5kg (1.1-11lbs) of dried beans. The beans inside the berries are then removed and treated before roasting.

Stem
The plants usually stand 1-3m (3-10ft) tall. Soil nutrients are absorbed and distributed via the stem.

Berries
Berries grow in clusters around the stem. They start off a dark-green shade, turning yellow, light-red and finally dark, glossy red. They are picked when they reach this final shade.

Anatomy of a coffee berry



Epidermis
A thin protective layer that covers the coffee seed.

Endocarp
The inner layer of the berry, the endocarp is membranous and surrounds the epidermis.

Pectin
Pectin consists of a set of acids and are present in most primary cell walls. It helps to bind cells.

Mesocarp
The pulp of the coffee berry.

Endosperm
Tissue produced inside the seed provides nutrition in the form of starch and contains oils and proteins.

Exocarp
Filled with oil glands and pigments, this is the outer protective skin.

The coffee beans dry on a concrete patio

EARTH'S LANDSCAPES

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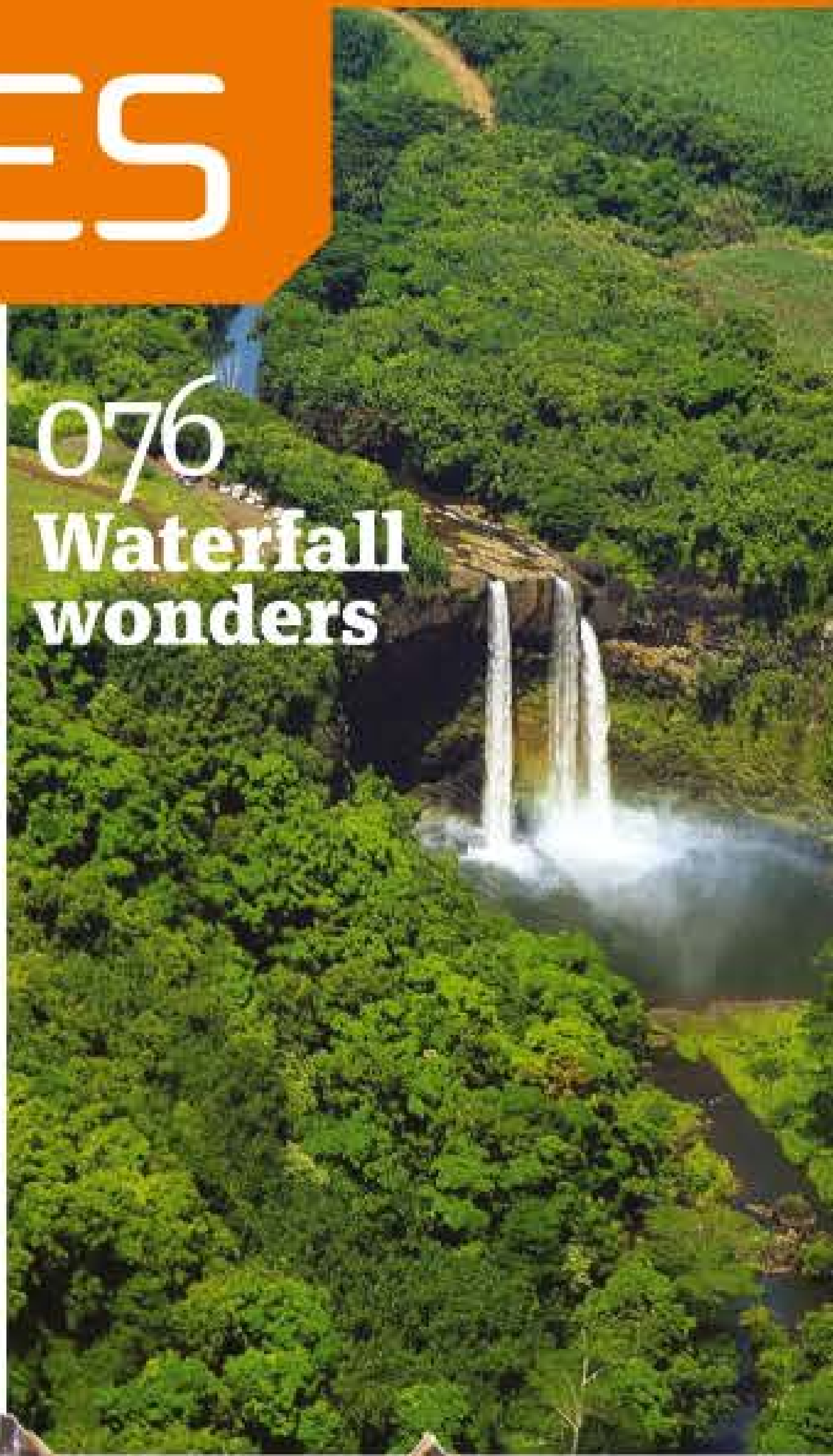
Marine habitats



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Explore our planet's wildest environments and make it out alive

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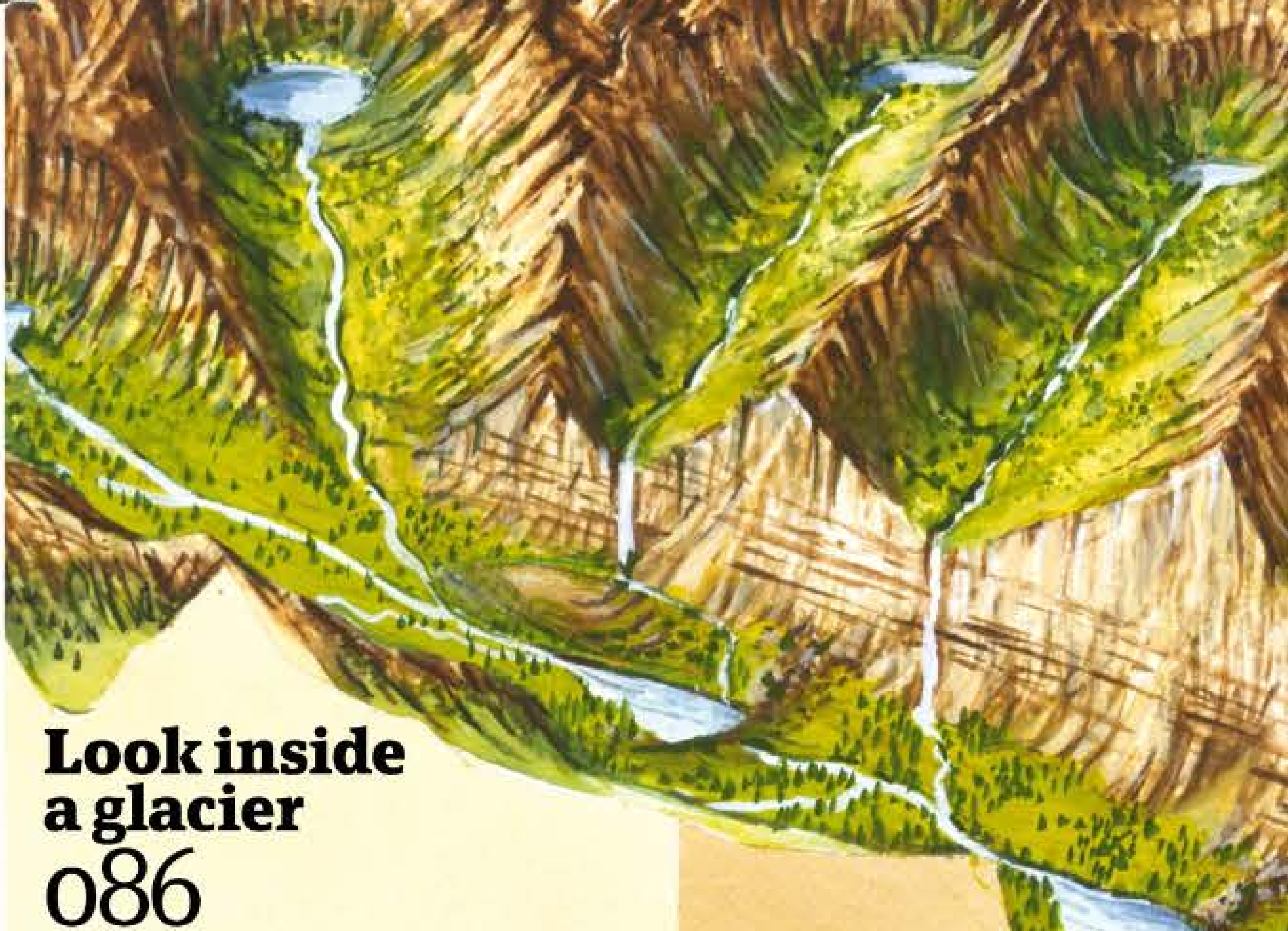

Look inside a glacier
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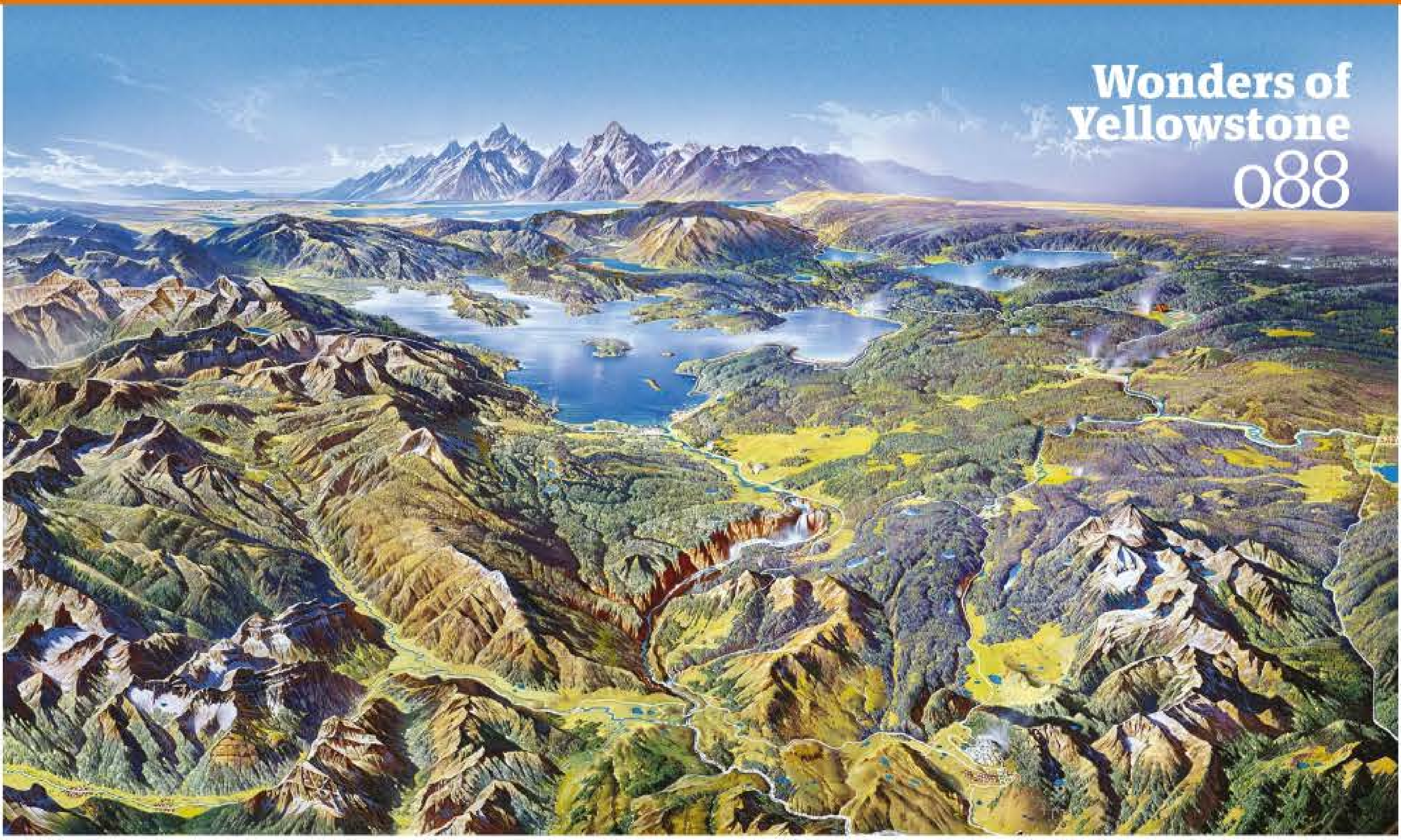

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SURVIVING EXTREME EARTH

The skills you need to journey into the wilderness and get out again alive

For many of us, the toughest conditions we'd ever have to face would probably be walking the dog in the bucketing rain. However, outside of the urban sprawl there are some places on Earth that aren't so hospitable to humans. While mankind has successfully populated large areas of the planet's land surface, there are still many places you wouldn't dare to venture unless you really enjoy a challenge or have just got horribly, horribly lost.

History is littered with people who have faced the biggest tests this planet has to offer, whether deliberately or accidentally, and lived to tell the tale, but many have fallen victim to frozen wastes or scorching plains. Even the best-prepared adventurers can come unstuck in the face of the amazing force of nature.

Over the next few pages we trek across deserts in search of water, dredge through jungles and scale icy mountains to uncover the dangers you're likely to come up against. Find out the equipment and skills needed to survive some of the most mind-boggling environments, where temperatures can plummet in hours, winds can reach breath-taking speeds and poisonous frogs can kill you where you stand.

We're not saying we will instantly turn you into the next Ranulph Fiennes, but it will hopefully give you a fighting chance should you find yourself in the depths of the Arctic Circle or in the middle of the Sahara.

Beat the freeze

How to stay alive when you're freezing to death

Earth's north and south extremities are among the most inhospitable places on the planet. Even in the summer, temperatures are freezing and winds can reach up to 327 kilometres (200 miles) per hour, so it's no wonder the cold is the biggest killer here. If you're trekking across snowy wastes, better pack your thermals. Shrug on multiple layers of breathable fleeces and keep them dry. Any water will instantly freeze, as will any exposed flesh. Even nose hairs and eyelashes start icing over in minutes, so covering up is key.

Your body will respond quickly to the heat loss by tightening blood vessels near your skin. This is the reason we look paler when we're cold and why our fingers and toes become numb. Meanwhile, your muscles will start moving involuntarily, causing you to shiver. It can boost heat production by up to five times, but that uses up a lot of energy so you'll need to keep eating and drinking. Consume six to eight litres (10.6 to 14 pints) of water every day and around 6,000 calories, three times the typical recommended daily allowance. You can get this by melting butter into your food or munching on chocolate and bacon, so it's not all bad!

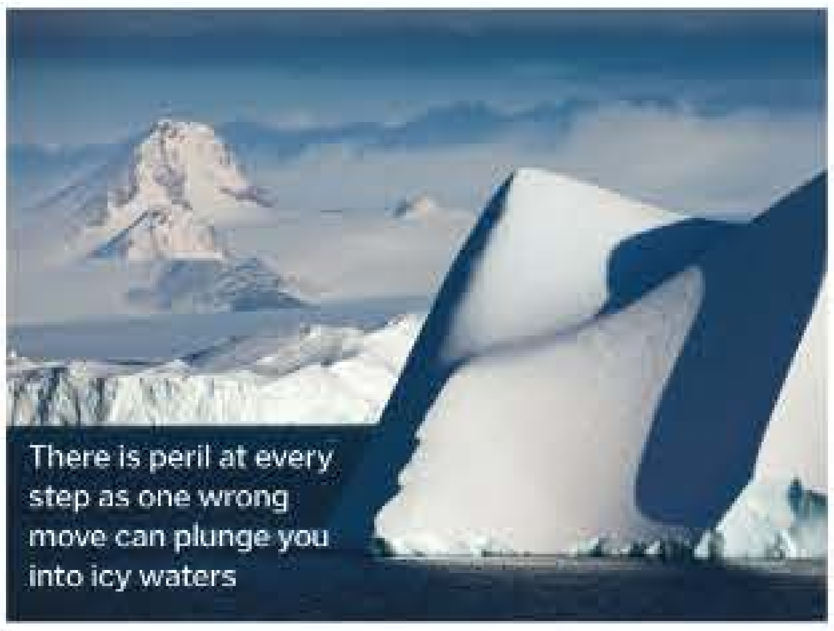
A word of warning, though: keep your eyes peeled. Hungry polar bears, particularly those with cubs to feed, can be very aggressive and they are masters of disguise. Flares and loud noises will often be enough to scare them away, but it's not a guarantee. You'll also need to watch your step as you go, as slipping through a crack in the ice can send you plummeting into the freezing cold ocean. It's generally safe to walk on white ice, but grey ice is only ten to 15 centimetres (four to six inches) thick and prone to cracking under pressure, while black ice is to be avoided at all costs since it will have only just formed. Tread very carefully, stay wrapped up and keep on the move if you want to have any hope of survival.

Amazing animal

The arctic fox is an incredible little animal, well adapted to living in one of the harshest environments on Earth. Its furry feet and short ears are ideally suited to conserving heat in the unforgiving, freezing environment. Its coat is also adaptable; while its habitat is snowy its fur is brilliant white, hiding it from both prey and predators. However, as the ice melts, its coat turns brown or grey to hide among the rocks of the region. The arctic fox is an omnivore, feasting on rodents, fish and birds, but it will also eat vegetation when meat is difficult to find.

The snowy wastes of the polar regions are difficult to navigate

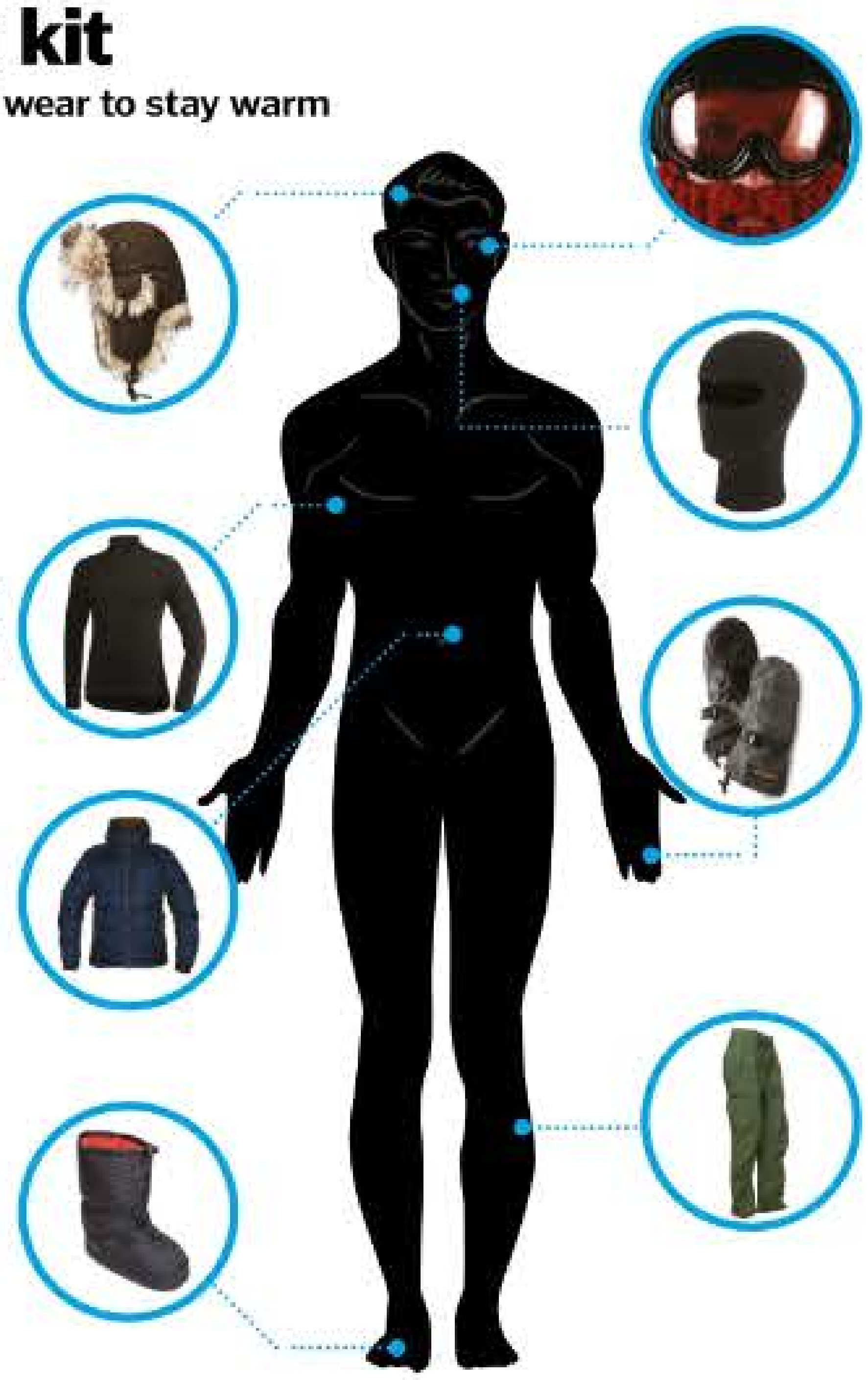
Polar bears are the Arctic's deadliest hunters


There is peril at every step as one wrong move can plunge you into icy waters

Little grows in this area so finding food is tough

Life-saving kit

A rundown of what to wear to stay warm



Hat
A hat with ear flaps that covers the head and neck is vital. A strap to secure it on the head will be useful in high winds.

Thermal shirt
Your base layer should be a thin, thermal insulating top that wicks any sweat away from your body.

Jacket
Your jacket will need to be both wind and waterproof to keep you dry and warm. Wrist holes in the cuffs keep it secured.

Boots
Warmth is vital – literally – so fleece-packed boots are good. Straps are better than laces but don't fasten them so tight it cuts off the blood supply.

Goggles
The best goggles have a photochromic lens to help ward off glare from the ice and make sure you see cracks and holes.

Balaclava
You'll need to cover up as much as possible, so a woollen balaclava will keep the most heat in.

Mittens
Although gloves offer more dexterity with actions, mittens are better as they keep your fingers together and much warmer.

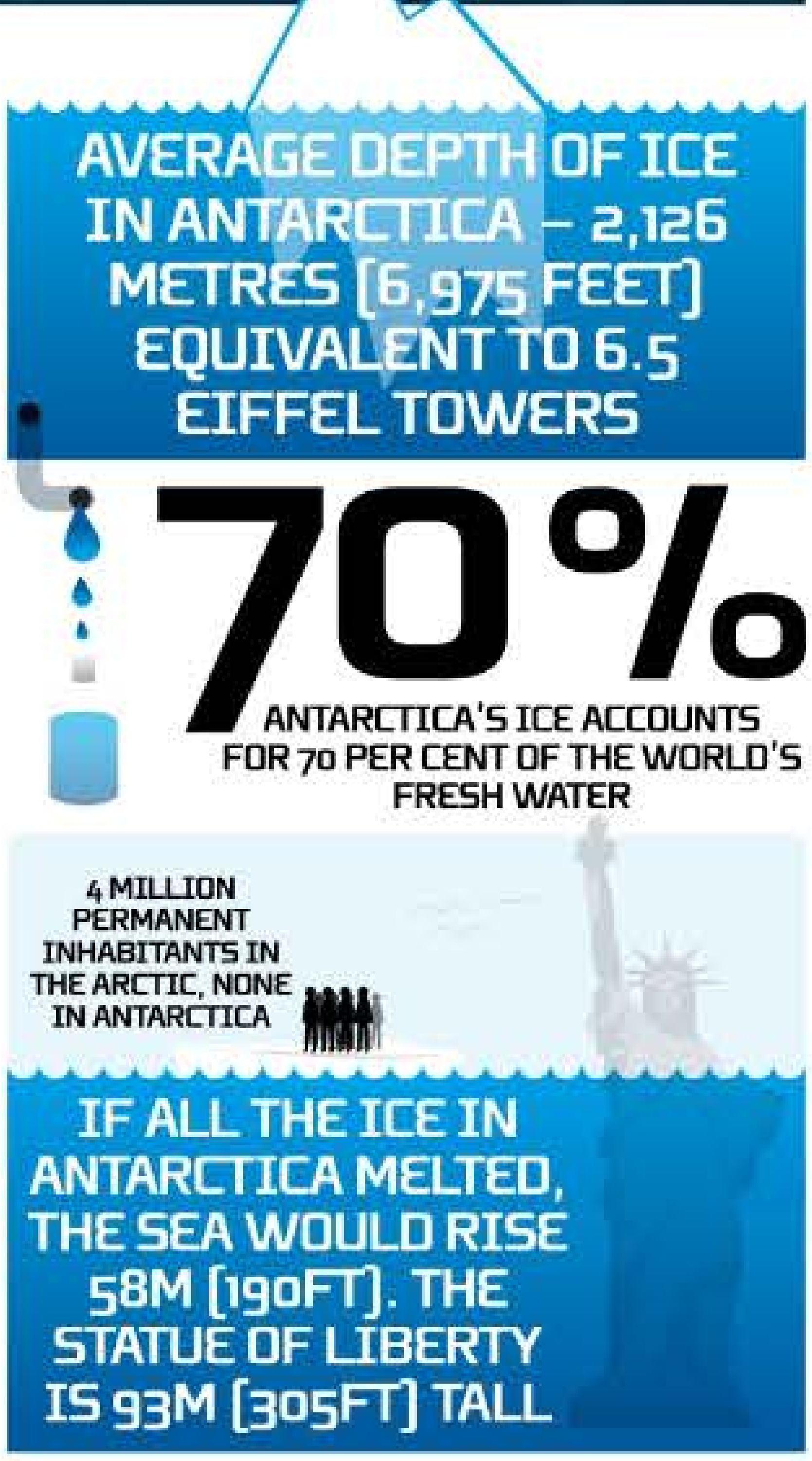
Trousers
Waterproof and windproof trousers are a must. Make sure they are also breathable, however, as you don't want your legs to become sweaty and lose valuable fluid.

DID YOU KNOW? *USA, Russia, Norway, Canada and Denmark all lay claim to territory in the Arctic, but none are allowed to own it*

Ice fishing

Make a hole in the ice with an auger – a kind of drill that bores large holes. The ice you bore on should be light grey and about 15 centimetres (six inches) deep. Produce a hole approximately 0.5 metres (1.5 feet) in diameter. Set up your chair one metre (three feet) away from the hole and hold your rod over the top of it, with the line dangling in the water. The rod should only be about a metre (three feet) long and made of a sturdy material. Drop the baited line down around two metres (seven feet) and wait for a bite. Reel it in and keep it chilled before cooking!

This simple tool can find you a life-saving source of food



AVERAGE DEPTH OF ICE IN ANTARCTICA – 2,126 METRES [6,975 FEET] EQUIVALENT TO 6.5 EIFFEL TOWERS

70%

ANTARCTICA'S ICE ACCOUNTS FOR 70 PER CENT OF THE WORLD'S FRESH WATER

4 MILLION PERMANENT INHABITANTS IN THE ARCTIC, NONE IN ANTARCTICA

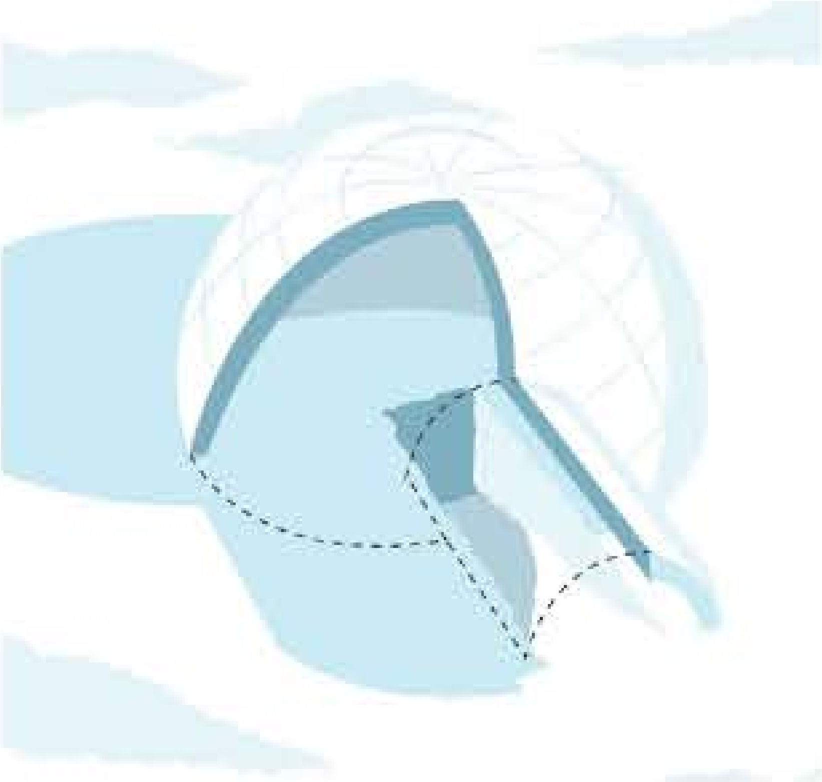
IF ALL THE ICE IN ANTARCTICA MELTED, THE SEA WOULD RISE 58M [190FT]. THE STATUE OF LIBERTY IS 93M [305FT] TALL

Survive the night

Build an igloo for protection

Find your spot

The first trick to making your igloo is to build it on the side of a slope. This will mean less building for you to do. Dig a trench in the snow around 0.6m (2ft) deep. Get in and slice out blocks of packed ice from either side of the trench to ensure they are nice and uniform.



Dig yourself in

Dig another trench into the side of the hill. It should be about 0.5 metres (1.6 feet) wide. This is the entrance trench. Leave a gap and dig another hole, but don't make it as deep as the entrance trench. This is your sleeping chamber, so make sure you fit in it!

Construct the walls

Stack the ice blocks in a circle around the sleeping trench, leaving a gap around the entrance trench. Over the entrance trench, stack the blocks in a semicircle. Make the entrance tunnel as small as possible to minimise heat loss. Rub water over the blocks to fuse them together.

Get out alive

Uncovering the dangers that lurk beneath the canopy of trees

Few places on Earth house quite as many things that can kill you in so many ways as the jungle. From snakes to poisonous frogs, berries to rivers, anyone walking through the jungle needs to have their wits about them at all times.

The most obvious threat will come from big animals like tigers and jaguars that inhabit the jungles of India and the rainforests of South America respectively. Your best bet for evading these huge predators is to stand still and hope you weren't seen, or run and hide. If you are spotted, make yourself as big as possible and shout loudly as this will surprise and intimidate them.

Don't be fooled into thinking the smaller critters pose less of a threat, though. Many can be deadlier than the big cats. The golden poison dart frog is particularly lethal to humans, as it has enough poison to kill ten adults. The poison is held in their skin, so eating or even touching one could have disastrous consequences. Add in the dangers of snakes, mosquitos, piranhas, crocodiles and bears, the jungle is not a place for the faint of heart. Take plenty of DEET-based insect repellent and make lots of noise as you travel so as to ward off creatures that would attack you out of fear or surprise.

While on your travels, be on the lookout for your next meal. On the menu will be fruit, plants, insects and fish, but you'll need a book to help weed out the edible from the poisonous. Avoid anything that's brightly coloured, because this is often an evolved defence mechanism to warn against eating that particular plant.

But while it's possible to survive for about 60 days without food in warm conditions, you'll last less than 72 hours without water. Always ensure you have a filtration device or water purification tablets to make the water safe, or catch rain before it has hit the ground to prevent catching diseases like cholera.

Although there are a multitude of things that can kill you in the jungle, being clued up on what you can and can't eat and how to avoid predator attacks will help enormously. If you're lost and ready to scream "Get me out of here!" then following water will take you out of the jungle to the end of the waterway. Ant and Dec almost certainly won't be there to meet you.

Tigers in the jungles of India are deadly predators

10

THE NUMBER OF ADULTS A GOLDEN POISON FROG COULD KILL IN ONE GO

Amazing animal

Bonobo monkeys are found in the jungles of the DR Congo and are one of our closest relatives. They share over 98 per cent of our DNA and have an astonishing ability to mimic human behaviour, including using tools and solving problems.

They have adapted superbly to life in the jungle, surviving on a varied diet of fruit, plant life small rodents, insects, and even soil. This flexibility means they will never go hungry.

They are extremely social animals, living together in groups of up to 100. The females move from group to group to prevent inbreeding and the males stay in their social groups for life.

DID YOU KNOW? *Earth's largest rodent, the capybara, lives in South American jungles and can weigh as much as an adult human*

Avoid man-eating predators

Three steps to remaining undetected in the jungle

Cover your tracks

Predators like big cats are excellent trackers and they'll be keen to find you, especially if it's dinnertime. Walking in water will stop physical evidence of your movements, giving you a better chance of going undetected.

Camouflage

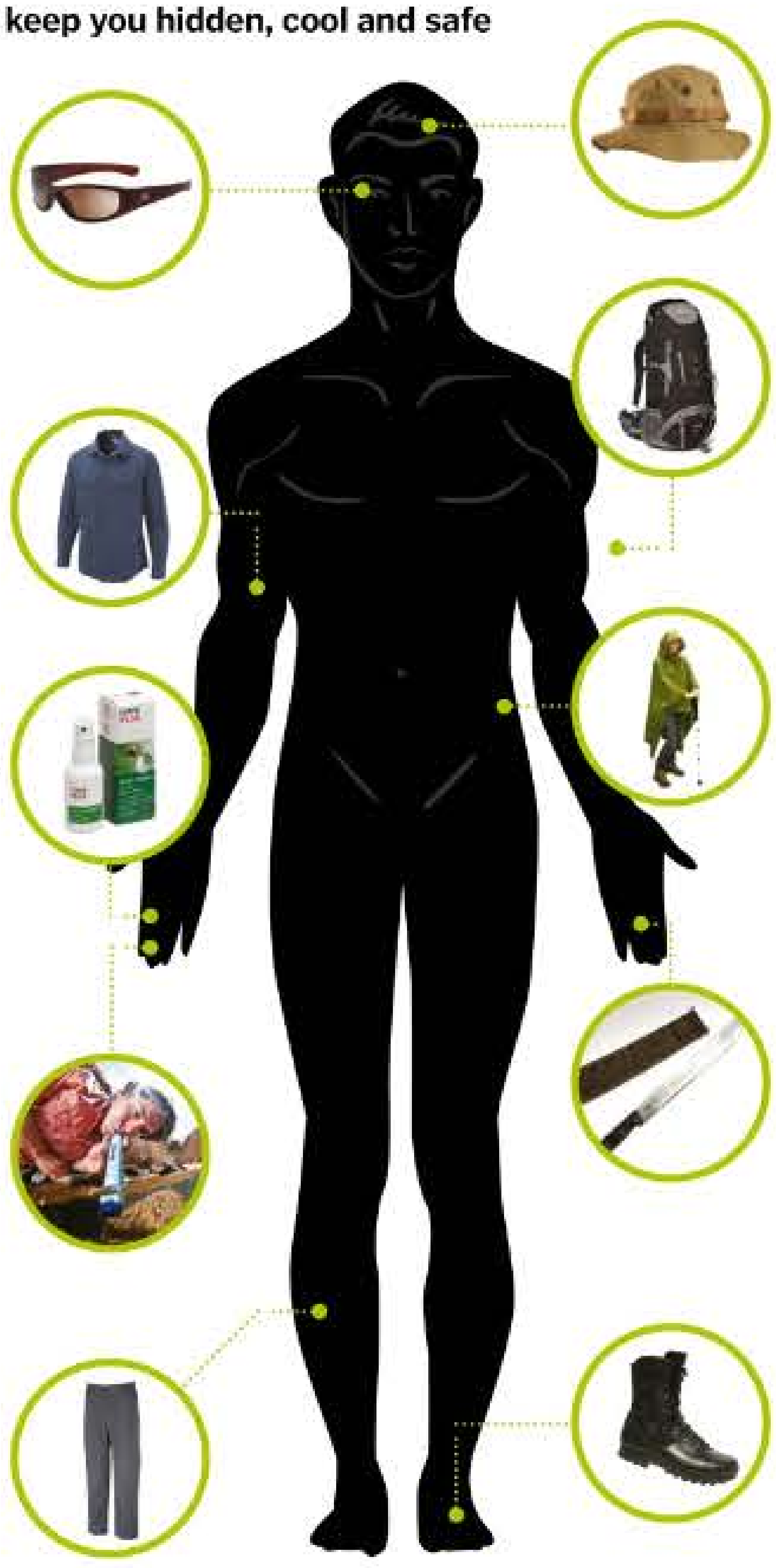
Hide yourself as you walk through the jungle using camouflage. If you don't have a specific outfit, coat yourself with mud and attaching leaves and foliage to your body will make you less likely to be spotted.

Cover your scent

Jackets lined with charcoal are excellent for preventing your natural odours from escaping into the environment. Otherwise, cover yourself in things like mud and strong smelling plants to mask your scent.

Jungle protection

The clothes and kit to keep you hidden, cool and safe



Sunglasses

The sunlight can be incredibly strong so you'll need some sunglasses with UV filters.

Long sleeve shirt

A light, breathable fabric will keep you cool, but make it baggy so mosquitos can't get to your skin.

Bug spray

Mosquitos carry a huge array of diseases, not least malaria, so 100 per cent DEET spray is vital.

LifeStraw

This device really could save your life. The filter inside the straw wipes out 99.99 per cent of bacteria in dirty water.

Trousers

Length is key here. You can't let your ankles get exposed because that's where mosquitos especially love to bite.

Hat

A large brimmed hat will protect you from bugs falling from the trees and keep you relatively hidden from animals above you.

Backpack

You'll need your hands free so a backpack is crucial. It needs to be waterproof, blend in with the environment and be comfortable.

Poncho

Sudden downpours are features of jungle and rainforest life, so a lightweight, quick-drying poncho is useful.

Machete

The jungle is a tough landscape to negotiate, so a large knife or machete will help you work your way through the thick and difficult undergrowth.

Boots

Your shoes don't want to be too thick and heavy because they'll wear you down. Sturdy trainers or Wellington boots will surprisingly be enough.

The edibility test

If you aren't a trained botanist, you might struggle to identify which plants are safe to eat. That's where the universal edibility test comes into play. Eat nothing and drink only water for eight hours before the test.

Your first task is to split up the plant you are testing into its individual components, such as the stem, root, leaf, flower and bud. Crush each part of the plant and, one-by-one, rub them on your skin to see if you have a bad reaction to it. If your skin blisters or forms a rash, it's unlikely to be good to eat.

If it's good, the next stage is to boil the plant, if possible. Hold the plant on your lip for a few minutes, removing instantly if it begins to burn. Finally, if the plant has passed the test so far, place it on your tongue. Again, if it begins to feel painful or look bad, spit it out and wash your mouth thoroughly. Remember though, tasting bad isn't the same as being poisonous!

Chew it for around 15 minutes and, if all still feels good, swallow it. Don't eat anything else for eight hours and see if you have any bad reaction to what you've eaten. If you're good, you've found a potentially life-saving food source!

Escape scorching heat

How to survive the extreme temperatures of the desert

While the polar regions are always bitterly cold no matter what time of day it is, one of the major challenges in surviving the desert is dealing with the ridiculous changes in temperature. In the midday Sun, the mercury can reach as high as 50 degrees Celsius (122 degrees Fahrenheit) in the Sahara, but drop to below freezing by night. Your best bet is to wear a loose-fitting robe. This will let air circulate around the body and you won't get nearly as hot and sticky. At night, when the temperature plummets, you can wrap it around you for warmth.

It is vital that you protect your head. If you think a touch of sunburn from staying by the pool on holiday is bad, that's nothing compared to the effects of walking all day in the parched desert. Even if it means burning another part of your body, wrap something around your head and neck so you don't succumb to sunstroke, which can lead to hallucinations and fainting.

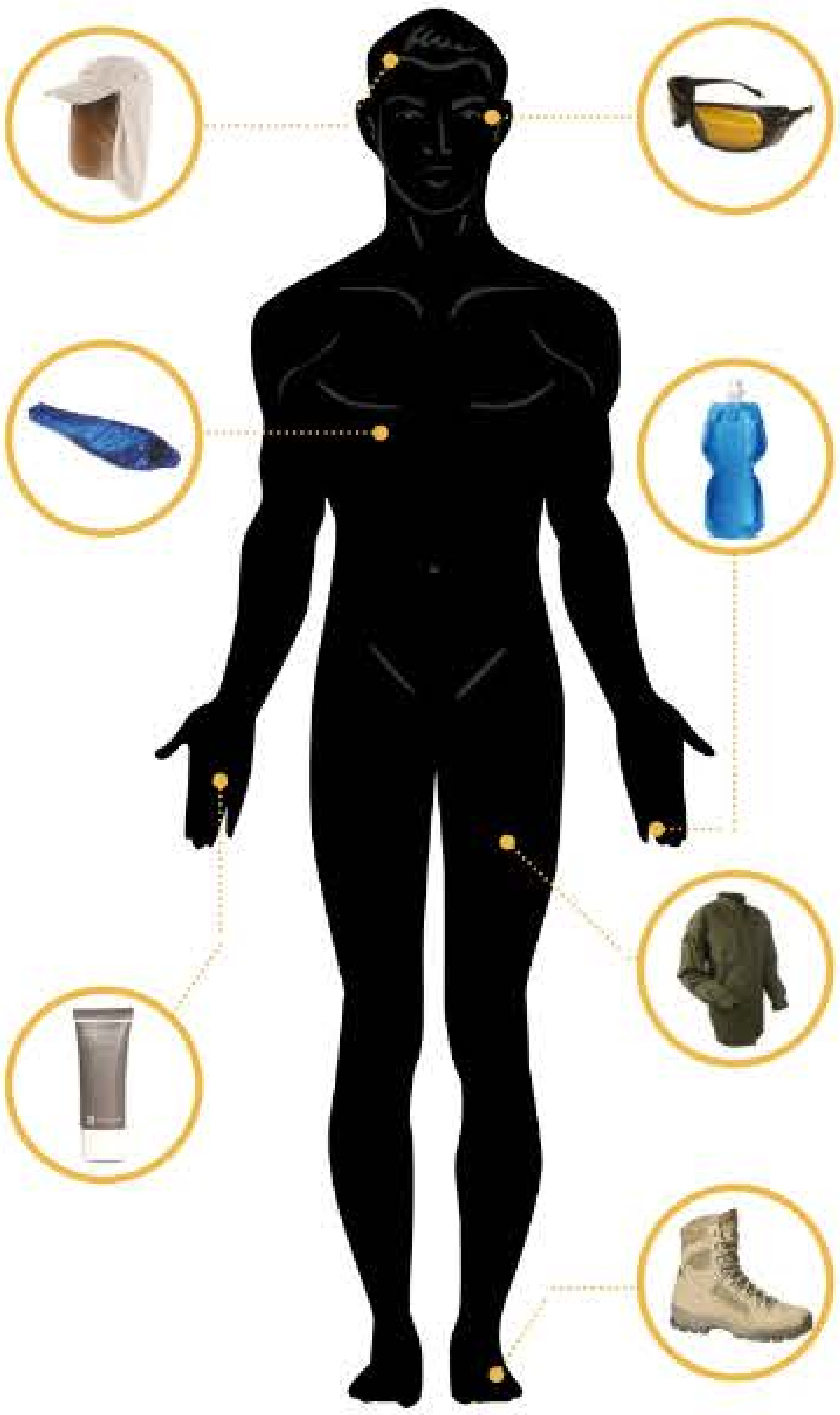
Other dangers in the desert will mostly come from scorpions. They hide in the sand and deliver a sting with their tail that can paralyse and eventually kill. Sturdy boots will protect you from these creepy crawlies, as well as make travelling over sand much easier. While they don't make great pets, scorpions do provide a crucial source of nutrition. Picking them up by the tail just behind the stinger is the safest method and it will give you vital protein for your journey. Just don't eat the tail.

In the desert, you'll need to adjust your body clock. Aim to shelter during the day and travel at night. This has the dual benefit of avoiding the scorching sun and keeping you active during the freezing night. It also means you can keep on the right track easily by following the stars, hopefully leading to civilisation.

Shelter can come in the form of large rocks or cliffs. Alternatively, you can dig a trench down into the cooler sand and use clothing or some other material you have available to form a canopy over the top, secured by rocks or sand. As long as it is at an angle and not touching you, you'll be protected from the Sun's glare.

Desert dress

The essentials to surviving in the hottest places on Earth



Headwear
If you don't have any headwear, you could suffer with heatstroke, so protect your face and neck.

Sleeping bag
A brightly coloured blanket will be useful as it would enable any search party to find you, will keep you protected in the day and warm at night.

Sun cream
The baking temperatures will burn you in no time at all, so a high factor sun cream will provide at least some protection.

Sunglasses
The desert throws up an awful lot of sand and glare, so sunglasses will be absolutely vital.

Water bottle
This will be your greatest friend. Take small, regular sips and if you ever find a water source, fill it up as much as possible.

Shirt
Your clothes will need to be as loose fitting as possible to minimise sweating and dehydration.

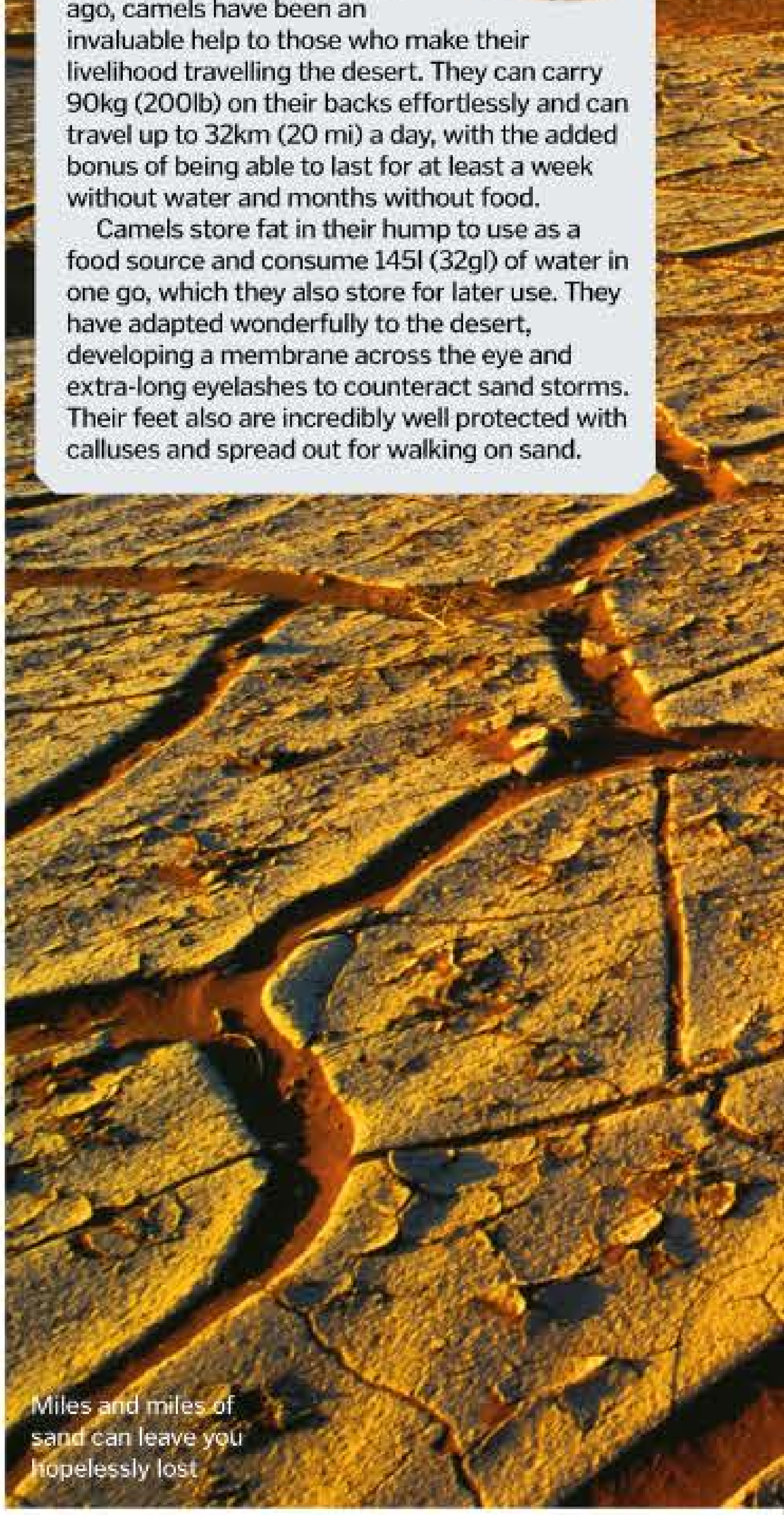
Footwear
Even though you'll be desperate for sandals, trainers or walking boots will give you grip and necessary protection.

Amazing animal

The camel is known as the ship of the desert, as this remarkable creature can travel without food or water for a long time.

Domesticated 3,000 years ago, camels have been an invaluable help to those who make their livelihood travelling the desert. They can carry 90kg (200lb) on their backs effortlessly and can travel up to 32km (20 mi) a day, with the added bonus of being able to last for at least a week without water and months without food.

Camels store fat in their hump to use as a food source and consume 145l (32gl) of water in one go, which they also store for later use. They have adapted wonderfully to the desert, developing a membrane across the eye and extra-long eyelashes to counteract sand storms. Their feet also are incredibly well protected with calluses and spread out for walking on sand.



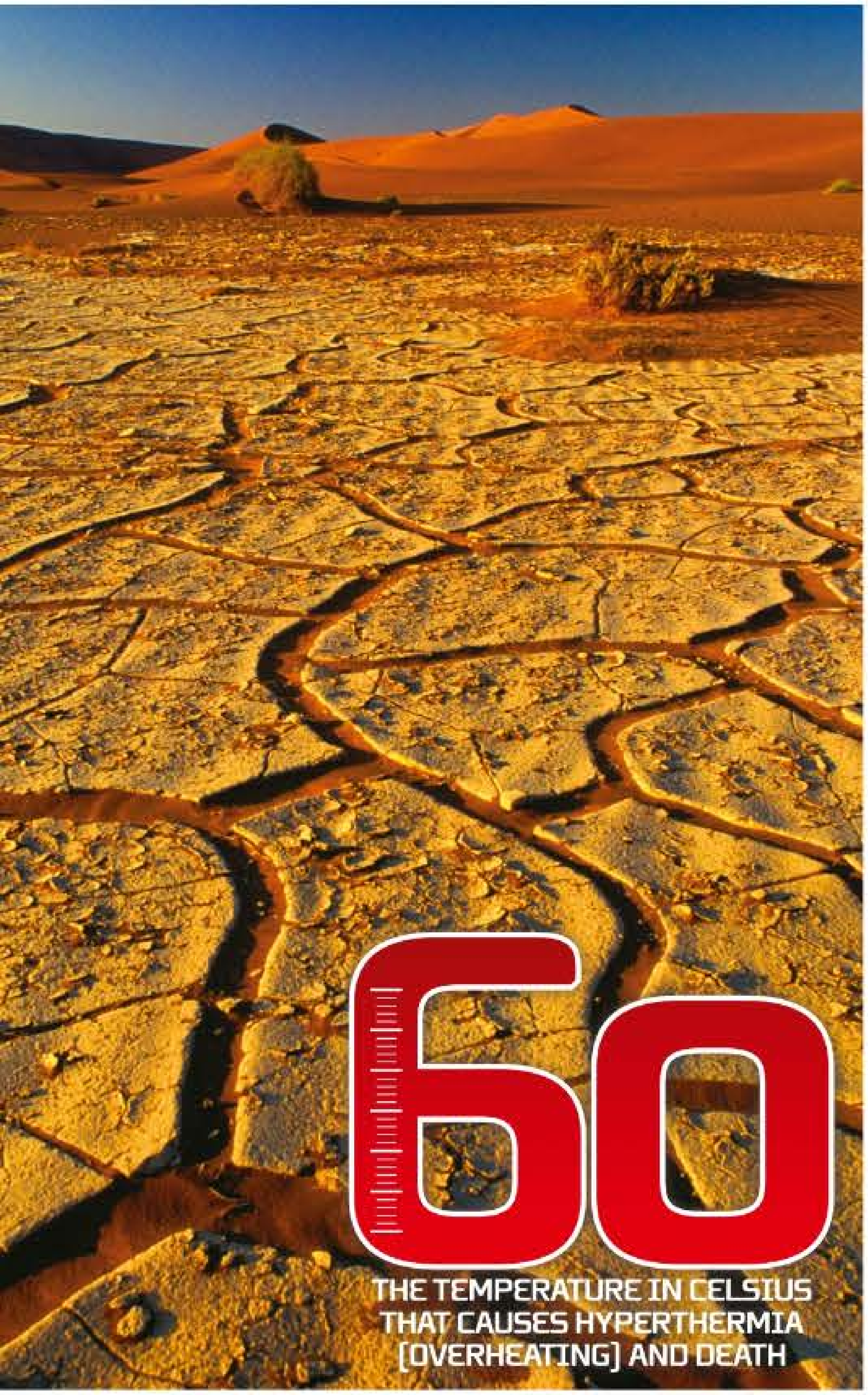
Miles and miles of sand can leave you hopelessly lost

Finding your way around

The desert is not only barren and featureless, but it is also a moving entity. Therefore, finding your way around is tough. The easiest way to find your way around is with a compass, but if that isn't available, travel at night and use Polaris, the North Star, as your makeshift compass.

Even though they are always shifting, sand dunes can also provide useful navigation hints. They always build up at 90 degrees to the direction of the wind, as the wind pushes sand upward to form them, so even when there's no wind, if you know the wind is northerly, the dunes will go east to west and you can use that information to navigate.

If you are lucky enough to have any landmarks, try and make a straight path between them so you know you are going in a straight line.



60

THE TEMPERATURE IN CELSIUS THAT CAUSES HYPERTHERMIA [OVERHEATING] AND DEATH

The plunging temperatures can leave you freezing cold without the right preparation

Fight extreme thirst

Locate the desert's most precious resource

Follow the wildlife

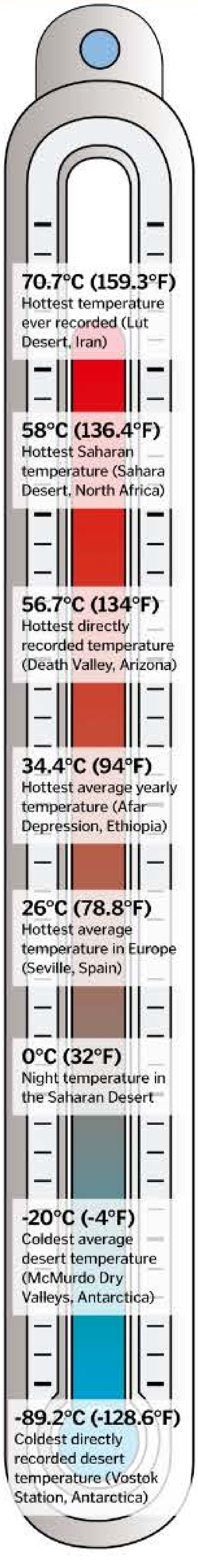
There are a number of birds and land animals that live in the desert and they all need water. Try and follow them wherever possible and hopefully they should lead you to a water source.

Shady cliffs

In your quest for precious shade, you might also be lucky enough to find water. Dips and ridges that face north could be housing puddles and pools in their shaded, cooler spots.

Grass is always greener

Plant life and vegetation means there is water around somewhere. Head down into valleys where there is plenty of greenery and even if there isn't a spring or pool around, you should be able to extract water from leaves or roots.



70.7°C (159.3°F)
Hottest temperature ever recorded (Lut Desert, Iran)

58°C (136.4°F)
Hottest Saharan temperature (Sahara Desert, North Africa)

56.7°C (134°F)
Hottest directly recorded temperature (Death Valley, Arizona)

34.4°C (94°F)
Hottest average yearly temperature (Afar Depression, Ethiopia)

26°C (78.8°F)
Hottest average temperature in Europe (Seville, Spain)

0°C (32°F)
Night temperature in the Saharan Desert

-20°C (-4°F)
Coldest average desert temperature (McMurdo Dry Valleys, Antarctica)

-89.2°C (-128.6°F)
Coldest directly recorded desert temperature (Vostok Station, Antarctica)

Battle life-threatening altitude

How to cross the world's most treacherous terrain

Mountains are the ultimate test of survival. They're prone to rapid changes in weather and it's near impossible to predict. Even if the base is warm and sunny, by the time you reach the summit, low cloud can blind you, rain can make the terrain slippery and the cold can freeze you.

Good preparation is essential and you'll need a lot of kit. Pack a rucksack with a map, compass and a flashlight or headtorch, along with a brightly coloured emergency blanket, and dress in thermals and waterproof and windproof clothing. You'll also need to keep well hydrated. A lack of fluid at high altitude will result in dizziness, intense headaches and even frostbite. If you don't have any water to hand, try to find a stream or melt some snow or ice to drink.

The altitude is a real issue for many mountaineers. As you climb higher, the air pressure reduces, meaning there is less oxygen for you to breathe. This lack of oxygen will cause your brain to reduce activity in all but the most important organs, making your limbs heavy and head dizzy. The most important thing to do is rest and re-oxygenate your body.

If you are trying to escape the mountain, the best way is to head downward, but this isn't always possible. Mountains have complicated structures and often there isn't an easy path down. If possible, put markers along your route to show where you have already been, to avoid walking in circles. As well as being potentially confusing, mountains also hide dangerous crevices. Keep your eyes peeled for breaks in the snow or ice and if you are ever unsure, try to find rocks or stones to throw in front of you that could give away a hidden abyss.

If the visibility does become too poor, the safest thing might be to bed down. Find a spot out of the wind and protected from any snow or rainfall, like a cave or overhanging cliff. Even though it might sound strange, pack your surroundings with snow, because it does have insulating properties. Pile yourself with as many layers as possible and this should provide the warmth so you can make it through the night and try to find your way out in the light.

Amazing animal

The mountain goat is amazingly adapted to life on the mountainside. Their hooves are curved and flexible to provide them more grip and traction on the treacherous slopes. Despite looking spindly and thin, their legs are actually very strong and they can leap surprisingly large distances.

They have two coats, a warm, woolly undercoat and a thinner but longer overcoat, which keeps the insulating undercoat dry. This system is how they can stand the cold temperatures long after bigger animals have given up and descended down the mountain in cold weather.

GoPros are a great way to record your adventure

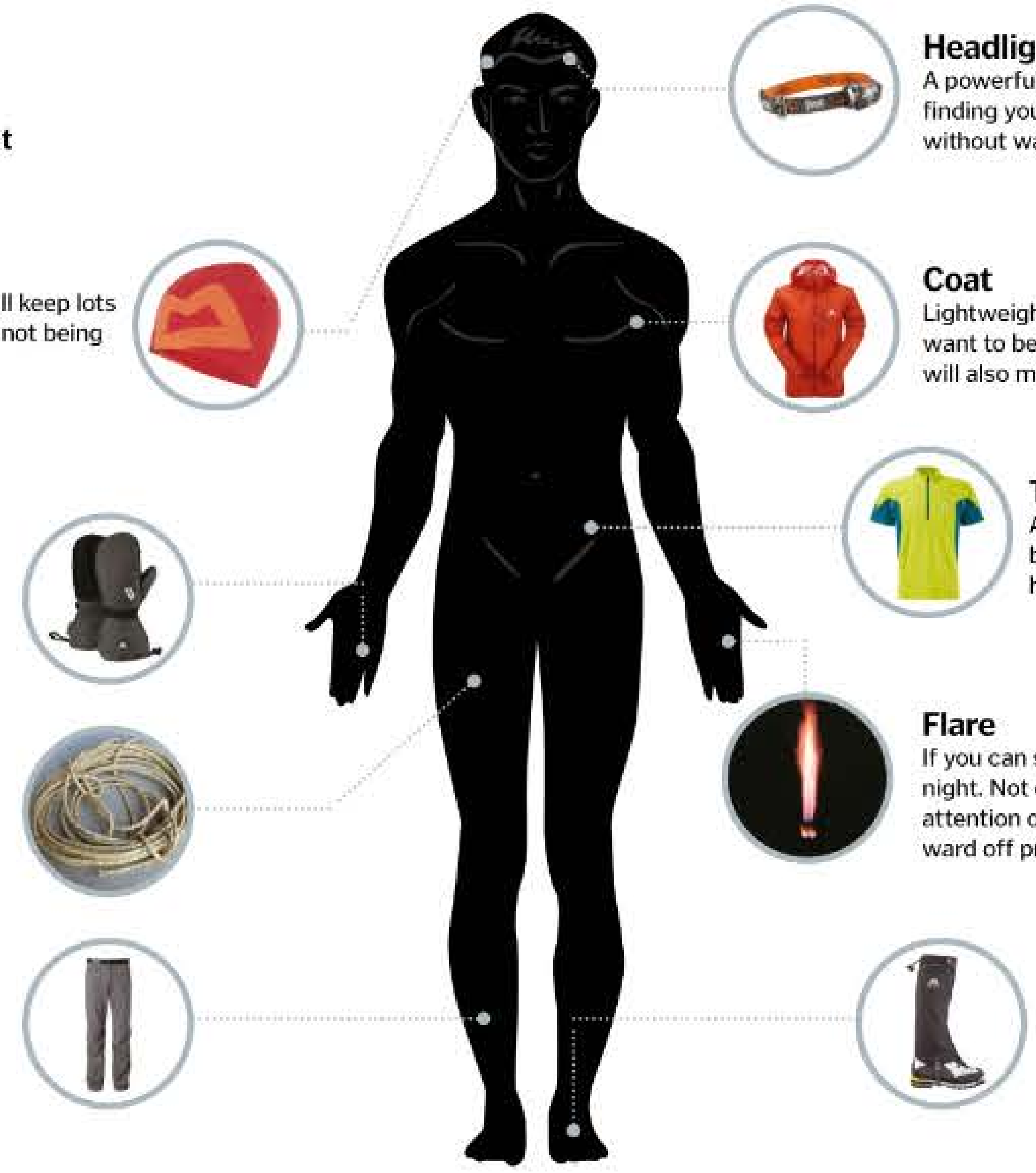
Keep a record

It's always handy to have a visual record of your travel by using a video recorder like the Hero3+ from GoPro. This camcorder is incredibly robust, lightweight and waterproof. It can also be attached onto helmets or bags, leaving your hands free to scale the treacherous mountainside.

Using a GoPro camera will also be useful as, once you get off the mountain to safety, you and a professional will be able to look over the footage, determine what went wrong and see how you could avoid getting stuck in the same situation again. The Hero3+ is available at www.camerajungle.co.uk.

Mountain gear

What you need to brave the harsh, mountainous environment



Beanie
A tight-fitting hat will keep lots of heat in as well as not being likely to fly away!

Mittens
Although it would be useful to have fingers available for gripping ledges, it's more important to have your fingers warming each other.

Rope
A strong and sturdy rope will help you protect yourself while asleep and also aid you in climbing or negotiating dangerous paths.

Trousers
You need to keep dry and have items accessible, so a pair of waterproof trousers with zipped pockets will be the most useful.

Headlight
A powerful headlight will be essential for finding your way around in darkness without wasting a hand on a torch.

Coat
Lightweight is key here because you don't want to be weighed down. Bright colours will also make you visible to rescuers.

T-shirt
A tight-fitting T-shirt made of breathable material will keep body heat in without making you sweat.

Flare
If you can send up a flare, do so at night. Not only will it attract the attention of rescuers, it might ward off predators.

Boots
A high-legged boot will keep the worst of the snow and water out, while the sole will need to be rugged and have tons of grip.

Keep the fire burning

How to warm up on the mountainside

Find some wood

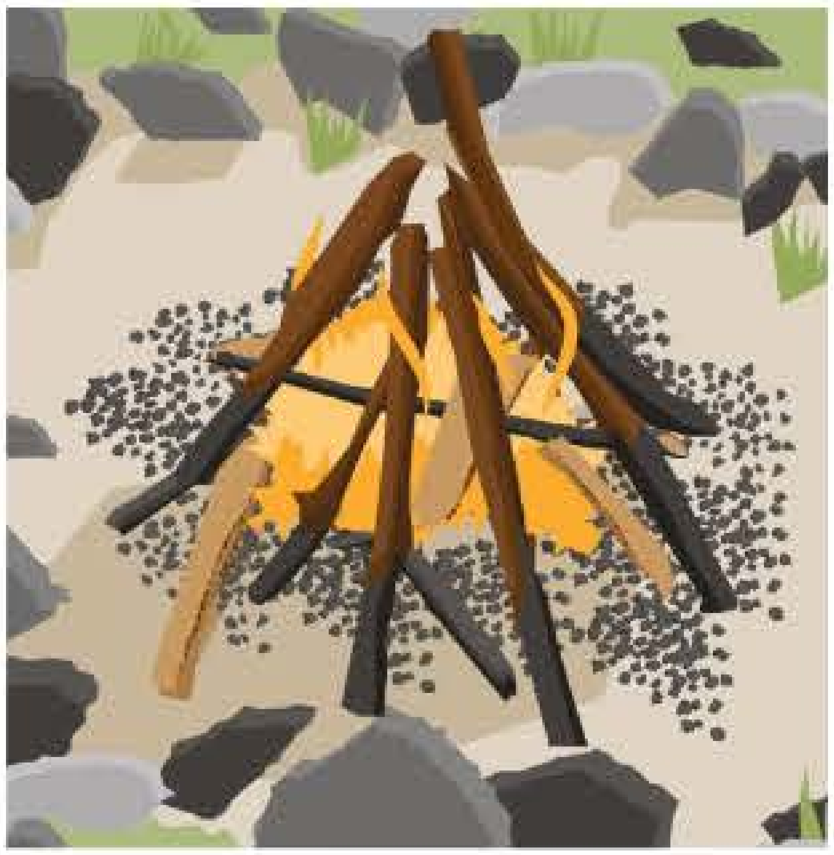
You'll want a variety of wood, from small sticks and twigs, all the way up to sizeable branches and logs. The smaller bits will light much more quickly while the bigger pieces will burn longer, hotter and form the bulk of the blaze.

Build your base

Dig a small pit in the ground. Surround it with stones so the fire doesn't get out of control. Place the smallest bits of wood at the bottom of the pile, but leave some gaps to keep the fire supplied with the oxygen it needs to burn.

Light the fire

Place the larger branches and logs at an upwards angle, allowing the air to circulate and ensuring all the wood is getting burned evenly. Make sure everything is connected so fire can transfer from one piece of wood to another.



The weather can turn in an instant, so make sure you're prepared for anything

7500

HEIGHT IN METRES AT WHICH NEARLY A THIRD OF CLIMBERS GET HALLUCINATIONS

Crevices and cracks await the unwary traveller

Waterfall wonders

The story behind the world's greatest waterfalls

Big waterfalls are among the most spectacular geological features on Earth. The thundering waters of Niagara Falls can fill an Olympic-sized pool every second. Visitors are drenched with spray and deafened by volumes reaching 100 decibels, equivalent to a rock concert.

A waterfall is simply a river or stream flowing down a cliff or rock steps. They commonly form when rivers flow downhill from hard to softer bedrock. The weak rock erodes faster, steepening the slope until a waterfall forms. The Iguazú Falls on the Argentina-Brazil border, for example, tumble over three layers of old resistant lava onto soft sedimentary rocks.

Any process that increases the gradient can generate waterfalls. A 1999 earthquake in Taiwan thrust up rock slabs along a fault in the Earth's crust, creating sharp drops along several rivers in the area. A series of new waterfalls appeared in minutes, some up to seven metres (23 feet) high – taller than a double-decker bus.

Many waterfalls were created by rivers of ice during past ice ages. These glaciers deepened big valleys, such as Milford Sound in New Zealand. The ice melted and shallow tributaries were left 'hanging' high above the main valley. Today the Bowen River joins Milford Sound at a waterfall 162 metres (531 feet) high, almost as tall as the Gherkin skyscraper in London.

Waterfalls vary enormously in their appearance. Some are frail ribbons of liquid while others are roaring torrents. All waterfalls are classed as cascades or cataracts. Cascades flow down irregular steps in the bedrock, while cataracts are more powerful and accompanied by river rapids.

Gigantic waterfalls seem ageless, but they last only a few thousands of years – a blink in geological time. Debris carried by the Iguazú River is slowly eroding the soft sediments at the base of the falls, causing the lava above to fracture and collapse. Erosion has caused the falls to retreat 28 kilometres (17 miles) upstream, leaving a gorge behind.

The erosional forces that birth waterfalls eventually destroy them. In around 50,000 years, there will be no Niagara Falls to visit. The Niagara River will have cut 32 kilometres (20 miles) back to its source at Lake Erie in North America and disappeared.

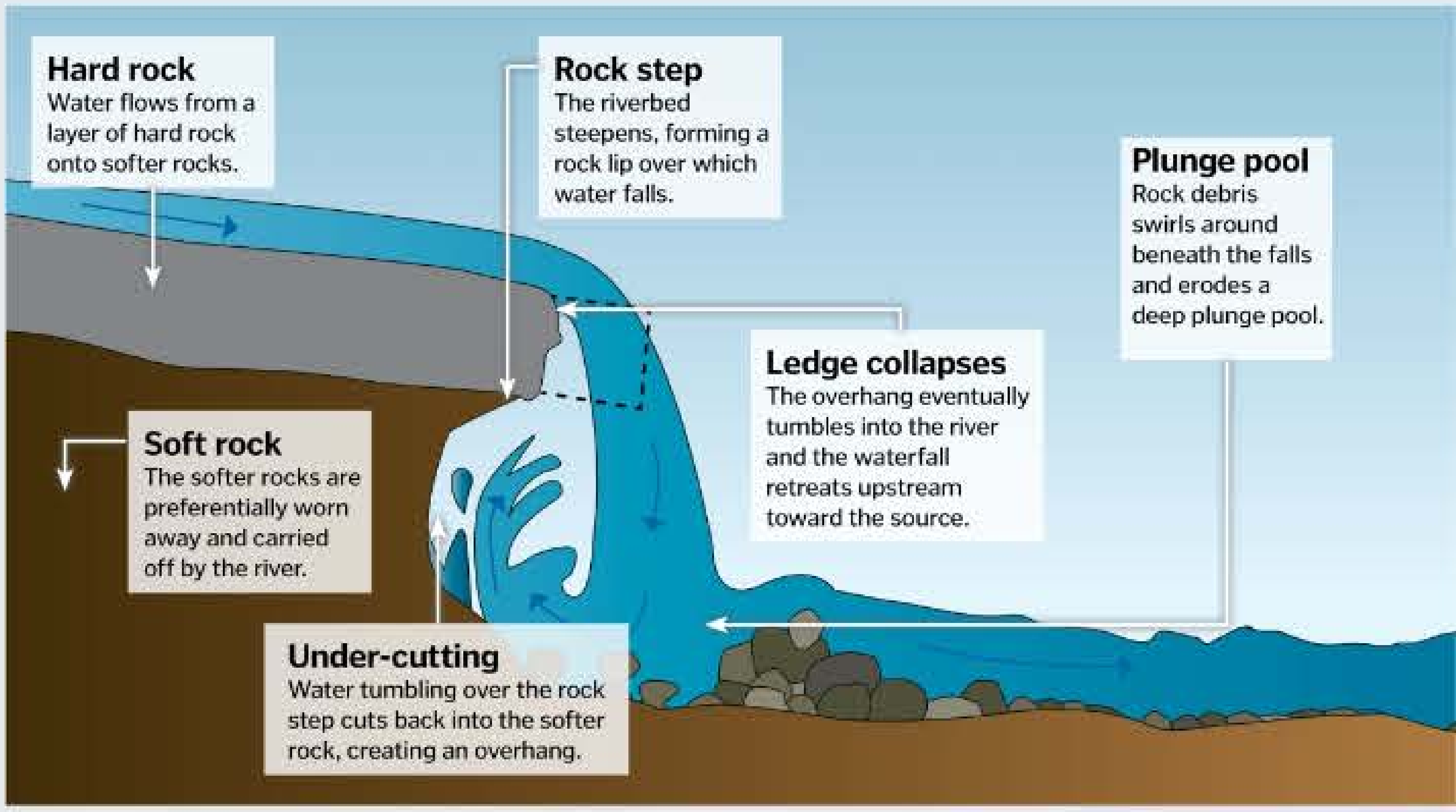
The sheer force and power of waterfalls makes them impossible to ignore. Daredevils across the centuries have used them for stunts.

DID YOU KNOW? *Fictional detective Sherlock Holmes fell into the Reichenbach Falls while fighting his nemesis Professor Moriarty*

Erosion power

Waterfalls appear to be permanent landscape features, but they are constantly changing thanks to the geological process of erosion. Erosion is the gradual wearing down of rock. Rivers transport sand, pebbles and even boulders, which act like sandpaper to grind down rock.

Waterfalls often form when rivers flow from hard to softer rocks. Over thousands of years, the softer rocks erode and the riverbed steepens. The river accelerates down the steep slope, which increases its erosive power. Eventually the slope is near vertical and the river begins cutting backward. As sections of the overhang collapse, the waterfall gradually moves upstream toward the river's source.



Hard rock
Water flows from a layer of hard rock onto softer rocks.

Rock step
The riverbed steepens, forming a rock lip over which water falls.

Plunge pool
Rock debris swirls around beneath the falls and erodes a deep plunge pool.

Ledge collapses
The overhang eventually tumbles into the river and the waterfall retreats upstream toward the source.

Soft rock
The softer rocks are preferentially worn away and carried off by the river.

Under-cutting
Water tumbling over the rock step cuts back into the softer rock, creating an overhang.

What is the biggest waterfall on Earth?

This is a tricky question as there is no standard way to judge waterfall size. Some use height or width, but the tallest one, Angel Falls, is only a few metres across at its ledge so is nowhere near the widest. Others group waterfalls into ten categories based on volume flowing over the drop.

Every method has problems. Boyoma Falls in the Congo is one of the biggest waterfall on Earth by volume, but some argue the turbulent waters are simply river rapids. Shape is a popular and easy-to-digest, but unscientific, way to classify waterfalls, as many of them fall (literally) into several different categories.

Horsetail

In horsetail waterfalls, the falling water stays in constant contact with the underlying rock, as it plunges over a near-vertical slope. One example is the famous Reichenbach Falls in Switzerland.

Block

A wide river tumbles over a cliff edge, forming a rectangular 'block' waterfall that is often wider than it is high. Famous examples include Victoria Falls in Africa and the Niagara Falls that straddles Canada and the United States.

Punchbowl

A river shoots through a narrow gap and cascades into a deep plunge pool. The name 'punchbowl' refers to the shape of the pool. An example of a punchbowl fall is Wailua Falls, found in Hawaii.

Plunge

Water spills straight over a ledge while barely touching the rock beneath. Angel Falls, found in Venezuela, is the world's highest uninterrupted waterfall and is a member of this waterfall category.

Tiered

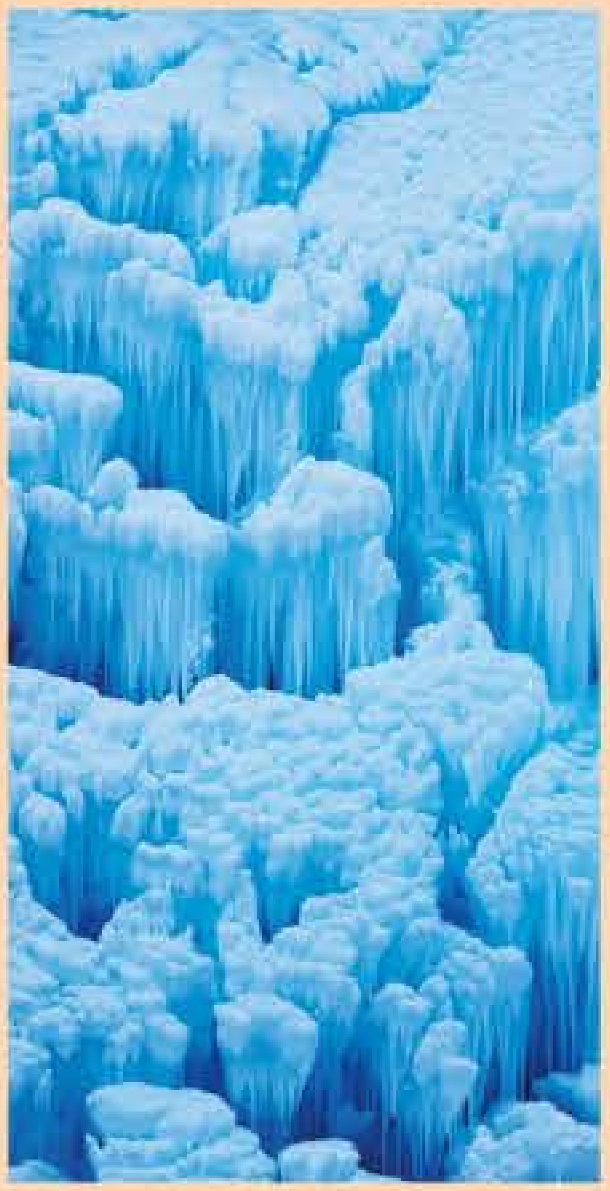
The waterfall has several drops, each with their own plunge pool. One example is Gullfoss, Iceland. Some tiered waterfalls, such as the Giant Staircase in the USA, can resemble several separate falls.

Chute

These resemble extreme rapids more than waterfalls. A pressurised frothy mass of water is forced through a suddenly narrower channel. An example is Barnafoss, a waterfall in Iceland.

Frozen waterfalls

Ice climbers in Colorado every winter tackle a frozen waterfall called the Fang – a free-standing icicle over 30m (100ft) tall and several metres wide. The idea of a frozen waterfall may seem strange. Rivers are slow to cool because their moving waters constantly mix and redistribute heat. When temperatures drop below freezing, water cools and ice crystals called frazil form. Only a few millimetres across, these start the freezing process by gluing together. Ice sticks to the bedrock or forms icicles on the rock lip. After a lengthy cold spell, the entire waterfall will eventually freeze.



The first tightrope walker crossed the Niagara Falls in 1859. Risk-takers have ridden the falls on jet skis, in huge rubber balls and even wooden barrels and many have died in the process. The steep drops mean waterfalls often pose a navigation problem. In the 19th century, the Welland Canal was built to bypass Niagara Falls.

People have long dreamed of harnessing the power and energy of the biggest falls. The first recorded attempt to use the swift waters above Niagara, for example, was in 1759 to power a water wheel and sawmill. Today many hydroelectric plants generate electricity near big waterfalls, such as the Sir Adam Beck Power Plants above Niagara Falls. River water is diverted downhill past propeller-like turbines. The rushing flow spins the turbine blades, creating renewable electricity. The bigger the drop, the faster the water, and the more energy it contains as a result.

Harnessing rivers for electricity can conflict with the natural beauty of their waterfalls. The Guaíra Falls on the Paraná River, probably the biggest waterfall by volume, were submerged in the 1980s by the building of the Itaipu hydroelectric dam.

These days, the conflict between power and nature is greater than ever. Dr Ryan Yonk is a professor of political science at Southern Utah University. According to him, "the demand for electricity generation in the developing world is not going away and it's going to ramp up."

Controversial hydroelectricity projects, like some in Asia, involve a trade-off between beauty and tackling climate change. Dr Yonk believes "the alternatives in those countries are likely to be very dirty coal."

Above Niagara Falls, treaties have balanced energy generation with iconic scenery since all the way back in 1909. During the summer, when most of the 12 million annual tourists visit the site, about half of the total water carried by the river must flow over the falls – an incredible 2,832 cubic metres per second (100,000 cubic feet per second).

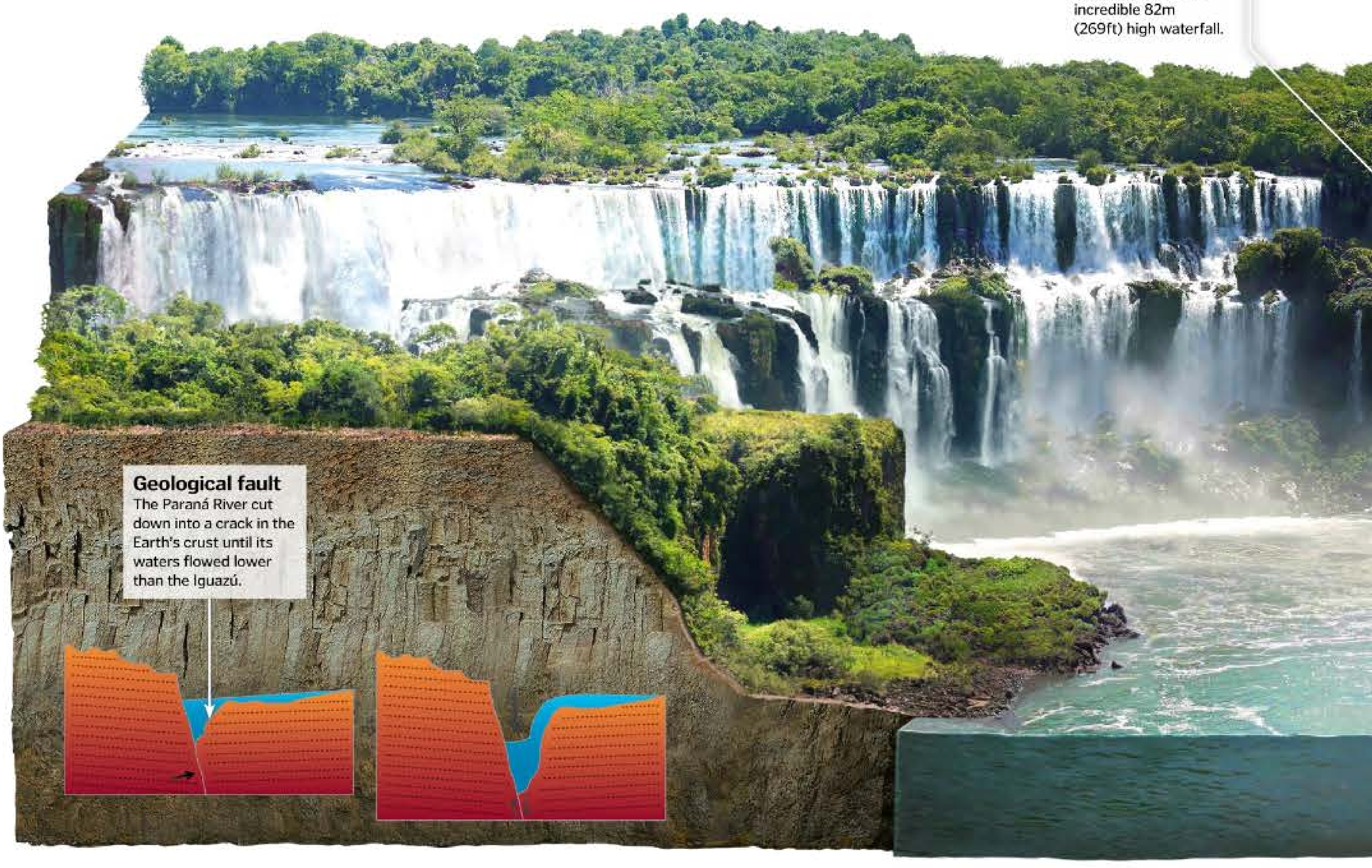
Yet these summer flow limits have a price. One study says the loss of potential electricity from the current treaty is 3.23 million megawatt hours each year – enough to run four million light bulbs.

Withdrawing more water could have benefits above hydropower generation. Samiha Tahseen is a civil engineering PhD student, studying Niagara flow at the University of Toronto. According to her, "you can reduce the erosion of the falls."

Another advantage to limiting the flow is that it minimises the mist that obstructs the beautiful view. Samiha adds: "There is no denying that the mist is dependent on the flow so if you decrease the flow of the falls a little bit, that helps."

The birth of Iguazú Falls

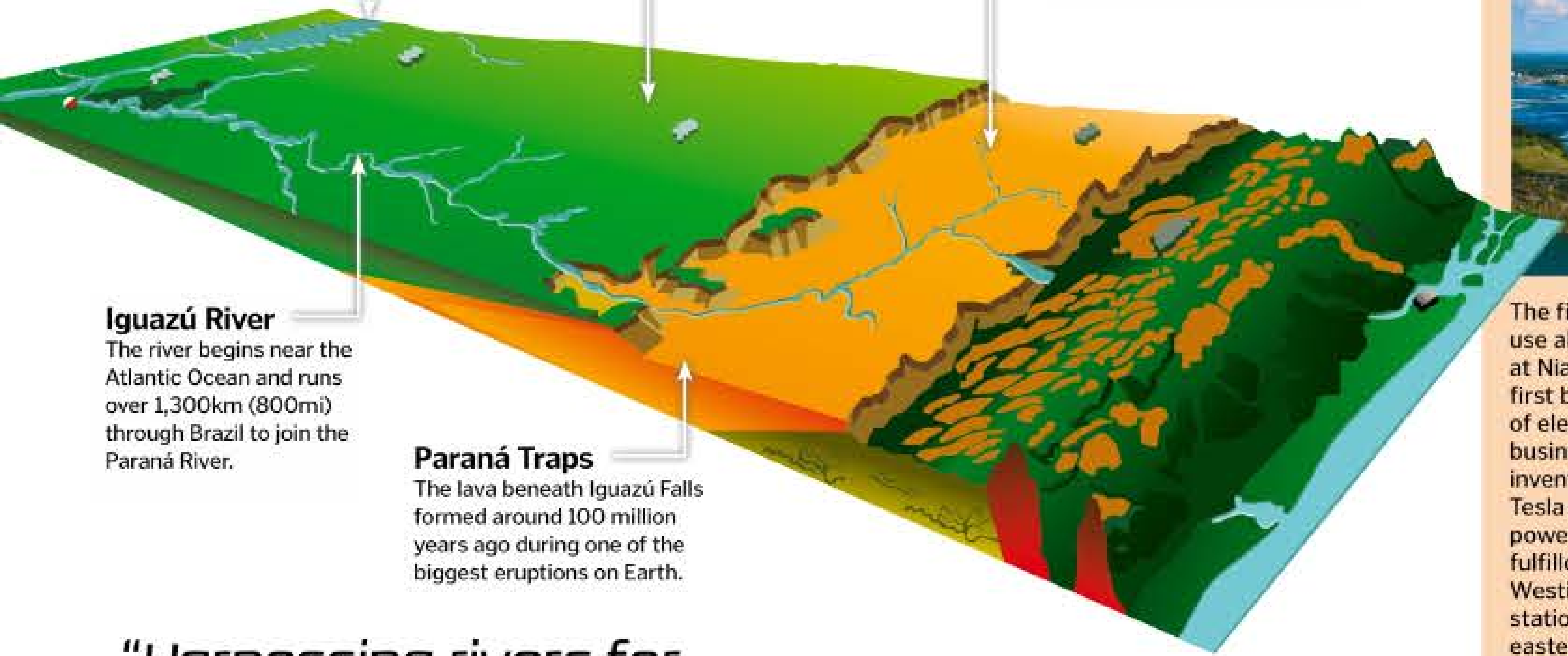
A gigantic eruption millions of years ago created a mighty waterfall on the Argentina-Brazil border



Iguazú Falls
The Iguazú River joins the Paraná River via a canyon beneath the incredible 82m (269ft) high waterfall.

Geological fault
The Paraná River cut down into a crack in the Earth's crust until its waters flowed lower than the Iguazú.

DID YOU KNOW? *The first person to go over Niagara Falls in a barrel was a 63-year-old teacher in 1901 – she survived*



Paraná River
The second-longest river in South America, after the Amazon.

Volcanic rock
A gigantic eruption covered the Iguazú area with layers of lava up to 1km (0.6mi) thick.

Sedimentary rocks
Beneath the layers of lava are softer, older rocks made from sandy sediments.

Iguazú River
The river begins near the Atlantic Ocean and runs over 1,300km (800mi) through Brazil to join the Paraná River.

Paraná Traps
The lava beneath Iguazú Falls formed around 100 million years ago during one of the biggest eruptions on Earth.

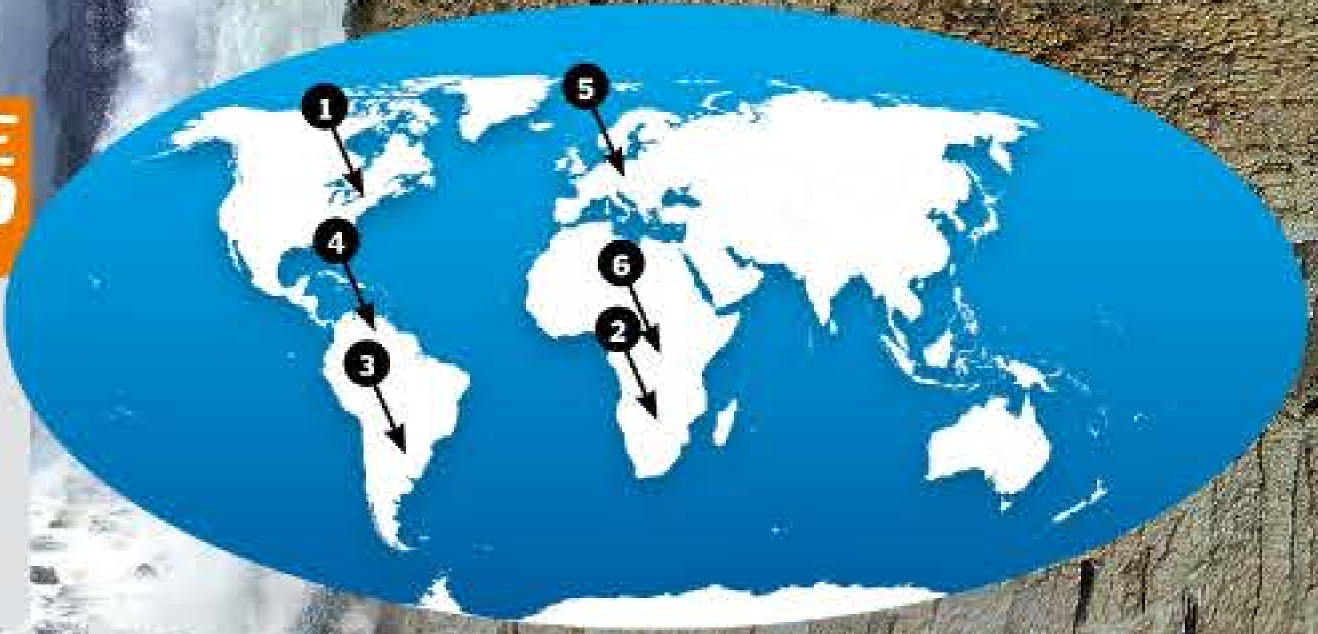
Electrifying Niagara Falls

The first large power station to use alternating current was built at Niagara Falls in 1895. It was the first big supplier of AC, the form of electricity that supplies businesses and homes today, invented by genius Nikola Tesla. Tesla imagined harnessing the power of the falls. His dream was fulfilled when industrialist George Westinghouse built a Niagara station big enough to supply the eastern United States. The plant was the largest of its age and, within a few years, its power lines electrified New York City.

> *"Harnessing rivers for electricity can conflict with the natural beauty of the falls"*

Step-like waterfall
Iguazú Falls tumble over three successive lava flows, giving them a staircase shape with several cascades.

ON THE MAP



Where in the world
1 Niagara
2 Victoria
3 Iguazú
4 Angel
5 Reichenbach
6 Boyoma

Antarctica explored

What's large, hostile and used to trial missions to Mars? Antarctica – the world's coolest continent

Antarctica is the world's last great wilderness and Earth's coldest, windiest, highest and driest continent. Around 98% of the land area lies buried beneath kilometres of snow and ice, yet Antarctica is – paradoxically – a desert. In fact, it is so inhospitable that no one lives there permanently, despite it being 25% bigger than Europe. This frozen continent remained unexplored until the 19th century. Unveiling its mysteries claimed many lives.

Antarctica is definitely worth a visit from your armchair, however, because it may also be Earth's quirkiest and most remarkable continent. Among its marvels is a river that flows inland, Mars-like valleys where NASA scientists test equipment for space missions, and perpetually dark lakes where bacteria may have survived unchanged since Antarctica had lush forests like the Brazilian rainforest. Living in and around the Southern Ocean that encircles Antarctica are fish with antifreeze in their blood, the world's biggest animal, and a giant penguin that survives nine weeks without eating during the harsh winter.

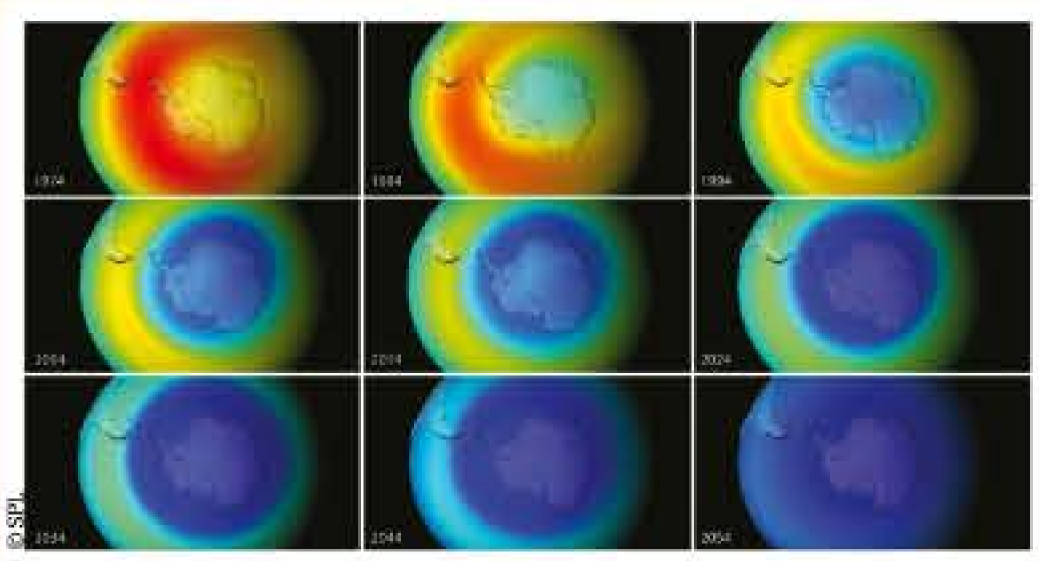
Antarctica is the chilliest place on Earth. At the Russian Vostok scientific research station in the cold, high continental interior, it can get cold enough for diesel fuel to freeze into icicles – even in summer. Vostok is the site of the coldest temperature ever recorded on Earth – an amazing -89.2°C (-128.6°F). The temperature in most freezers is only about -18°C (-0.4°F).

The continent is also Earth's windiest. Antarctica's ice cools the overlying air, which makes it sink. This cold, heavy air accelerates downhill, creating wind gusts of over 200 kilometres (124 miles) an hour. The sinking air at Vostok is so dry that some scientific researchers pack hospital IV (intravenous) drip bags to stop becoming dangerously dehydrated. Few clouds can form in the dry air, and most moisture falls as snow or ice crystals. Any snow that falls accumulates because it can't melt in the extreme cold.

If the climate wasn't harsh enough, Antarctica never sees daylight for part of the winter because the sun barely rises over the horizon. Even in summer, the Sun is feeble and low in the sky. The extreme cold partly explains why two huge ice sheets cloak Antarctica. The white ice cools it further by reflecting away about 80% of incoming sunlight. Together, these ice sheets contain around 70% of the world's fresh water. If they melted, global sea levels would rise by 70m (230ft) and swamp many of the world's major cities.

Antarctic mountains, pack ice and ice floes

© Jason Auch



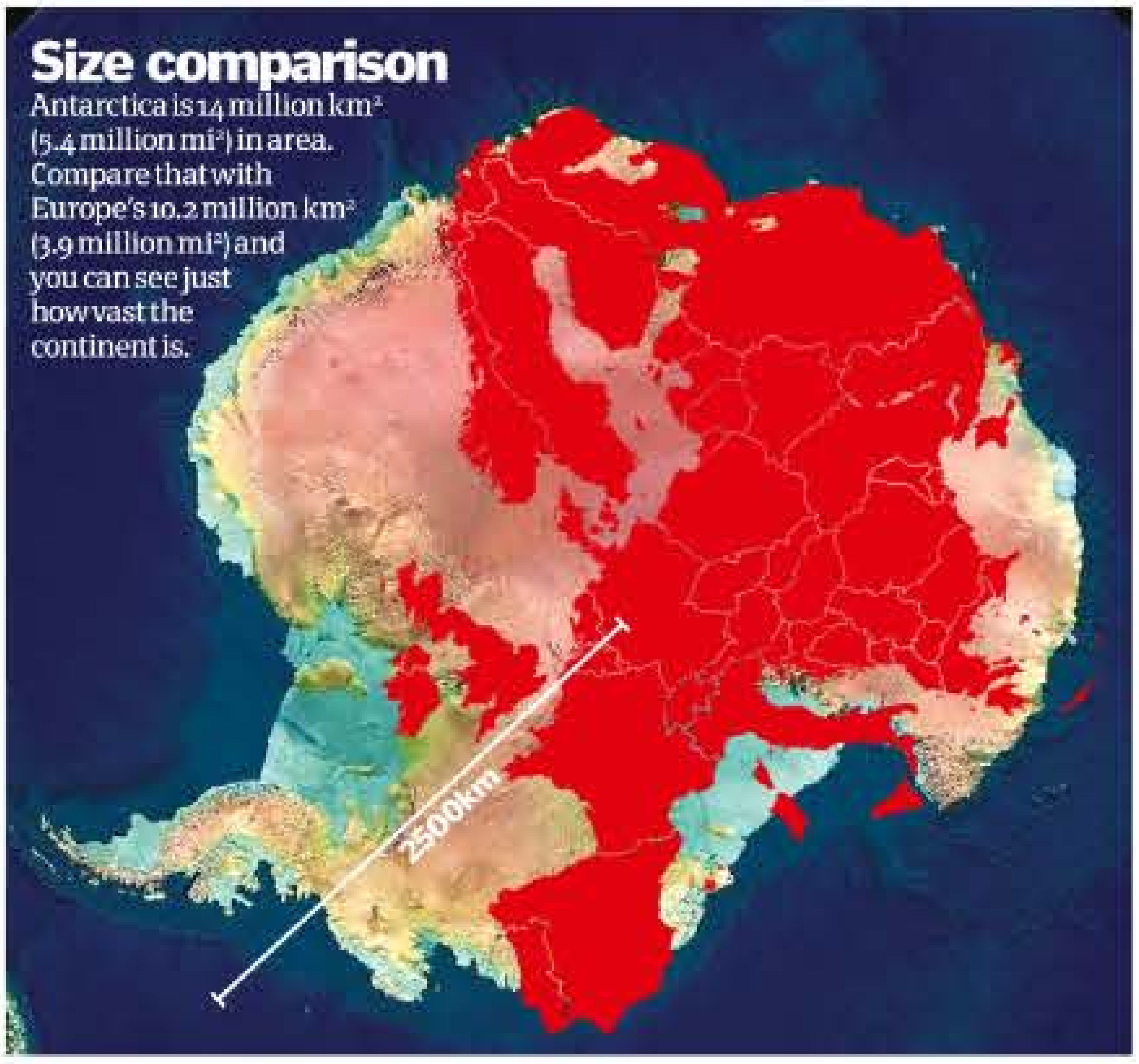
A world without ozone?

A 'hole' still exists over Antarctica

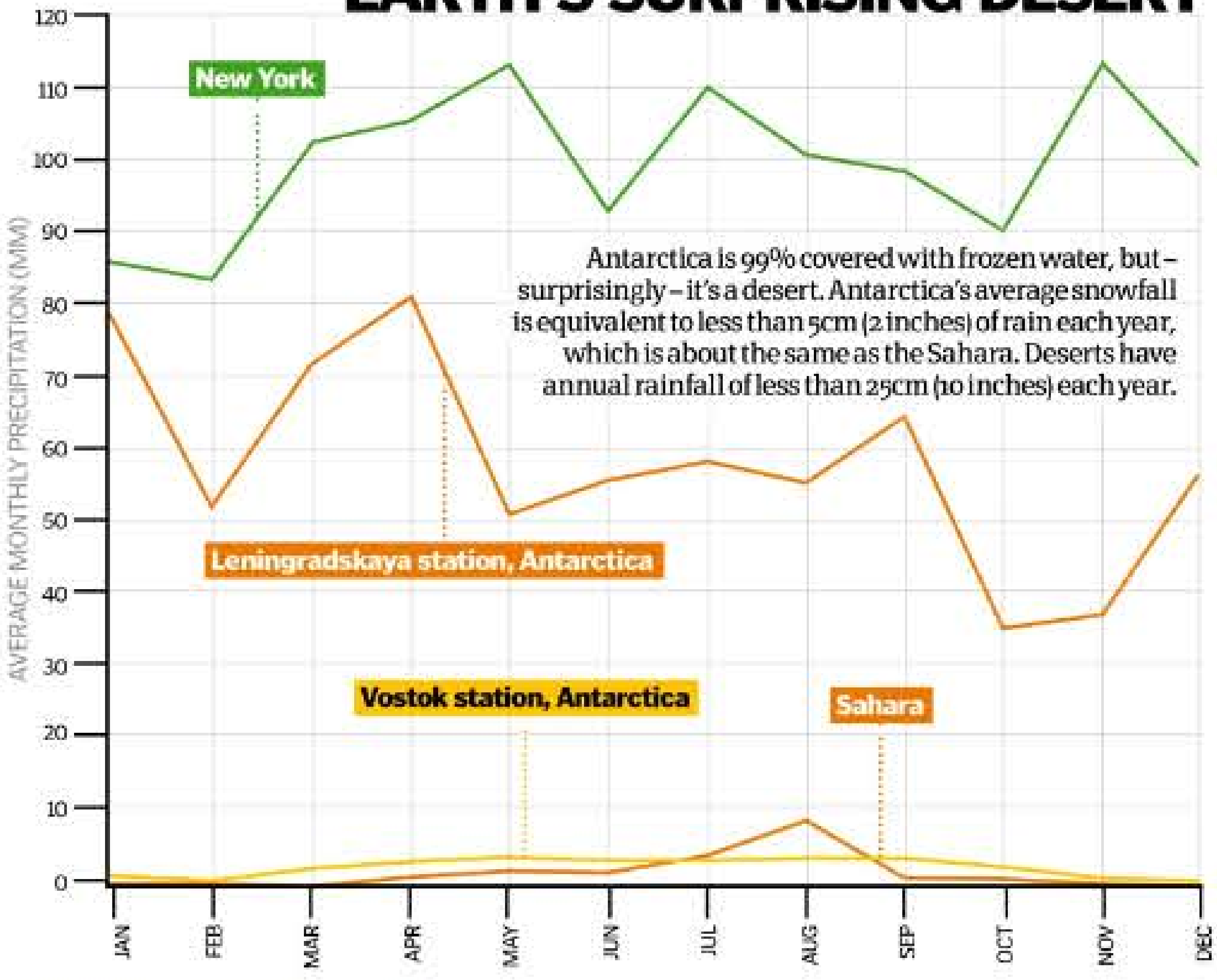
It's 2065, and skin cancer rates are soaring. Step outside in some cities and you'd be sunburned in ten minutes. That's the vision of NASA chemists, who predicted Earth's future if 193 countries hadn't agreed to stop producing CFCs in 1987. CFCs are man-made, chlorine-containing chemicals that destroy the Earth's ozone layer high in the atmosphere, which protects us from the sun's UV radiation. A 'hole' in this layer was discovered over Antarctica in the Eighties and persists today, because CFCs linger in the atmosphere for 50 to 100 years. The hole formed because the freezing winters allow unusual cold clouds to form. Chemical reactions on the cloud surface transform the chlorine in CFCs into an ozone-destroying form.

Size comparison

Antarctica is 14 million km^2 (5.4 million mi^2) in area. Compare that with Europe's 10.2 million km^2 (3.9 million mi^2) and you can see just how vast the continent is.



EARTH'S SURPRISING DESERT



Antarctica is 99% covered with frozen water, but – surprisingly – it's a desert. Antarctica's average snowfall is equivalent to less than 5cm (2 inches) of rain each year, which is about the same as the Sahara. Deserts have annual rainfall of less than 25cm (10 inches) each year.

"We're afraid if your name's not on the list, we can't let you in..."

The East Antarctic ice sheet is the largest on Earth, with ice more than three kilometres (two miles) thick in places. Under the ice sheet are some of the oldest rocks on Earth – at least 3,000 million years old. The West Antarctic ice sheet is smaller, and drained by huge rivers of ice or glaciers. These move slowly in Antarctica's interior, but accelerate to up to 100m (328ft) per year towards the coast. The fastest is Pine Island glacier, which can flow at more than three kilometres (two miles) per year. When these glaciers hit the sea, they form huge, floating sheets of ice attached to the land called 'ice shelves'. The biggest is the Ross Ice Shelf, which covers approximately the area of France and is several hundred metres thick.

One of the world's biggest mountain ranges separates the two ice sheets. The Transantarctic Mountains are more than two kilometres (1.2 miles) high and 3,300 kilometres (2,051 miles) long – more than three times the length of the European Alps. The mountains were formed around 55 million years ago during a period of volcanic and geological activity. Volcanoes like Mount Erebus are still active today.

Antarctica's main ice-free area is the McMurdo Dry Valleys, a region with conditions like Mars through which runs the continent's longest, largest river. The Onyx River carries summer meltwater 40 kilometres (25 miles) inland from coastal glaciers to feed Lake Vanda, which is saltier at its bottom than the Dead Sea. The salinity of Dry Valley lakes like Lake Vanda allows their deep water to stay liquid at temperatures that are below the freezing point of fresh water. Other strange Antarctic lakes include Lake Untersee in the East Antarctic interior, which has

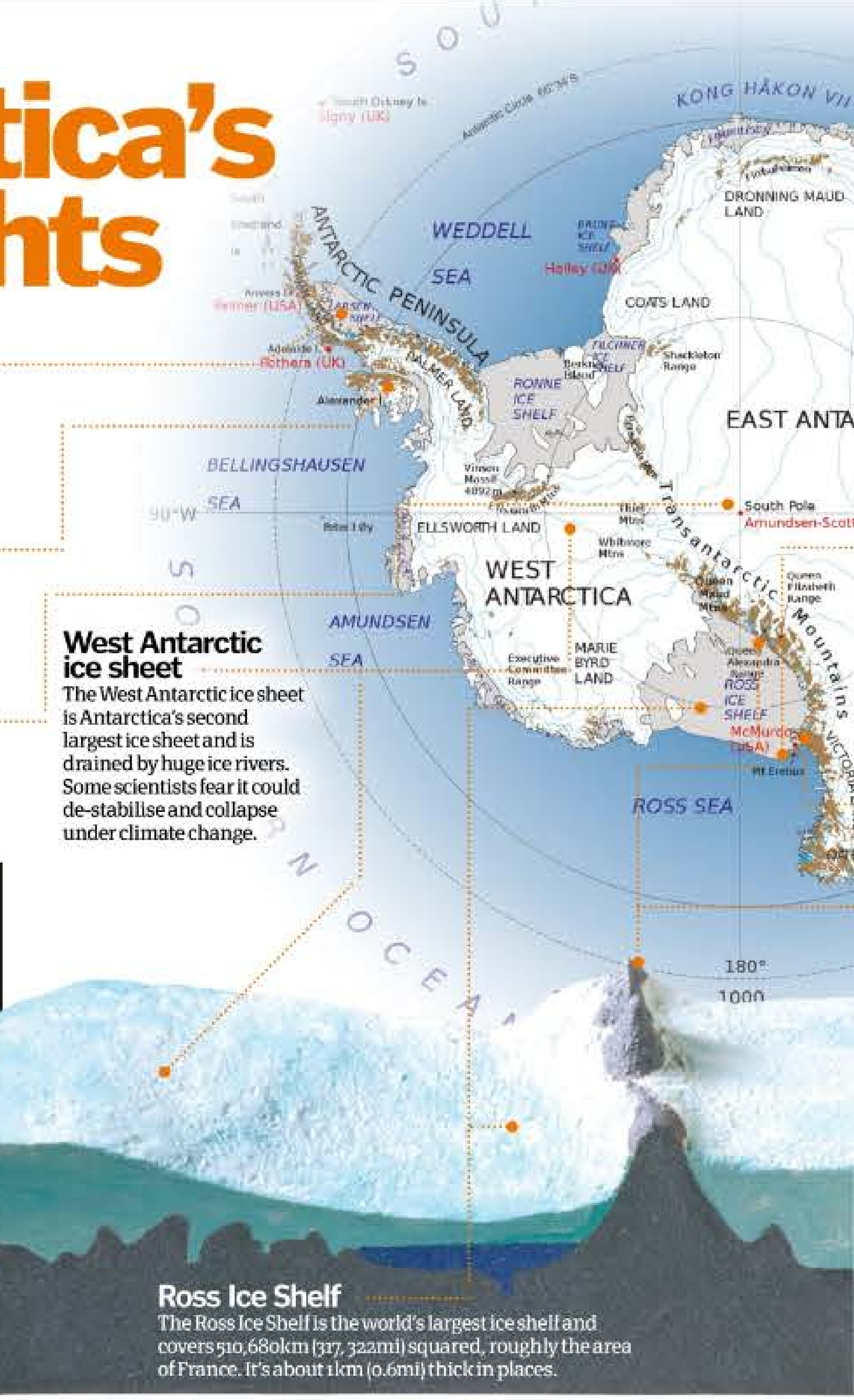
Antarctica's top sights

Larsen Ice Shelf
A Luxembourg-sized area of the Larsen Ice Shelf collapsed in only 35 days in 2002. Scientists said it was the first time the shelf had collapsed in 12,000 years.

Antarctic Peninsula
The Antarctic Peninsula is a mountain chain typically more than 2km (1.2mi) high that protrudes 1,334km (829mi) north towards South America. It's the warmest, wettest part of Antarctica.

South Pole
The geographic South Pole is where Earth's longitude lines converge. The striped ceremonial Pole where pictures are taken is about 90m (295ft) away from the real Pole, which is on a moving glacier.

West Antarctic ice sheet
The West Antarctic ice sheet is Antarctica's second largest ice sheet and is drained by huge ice rivers. Some scientists fear it could de-stabilise and collapse under climate change.



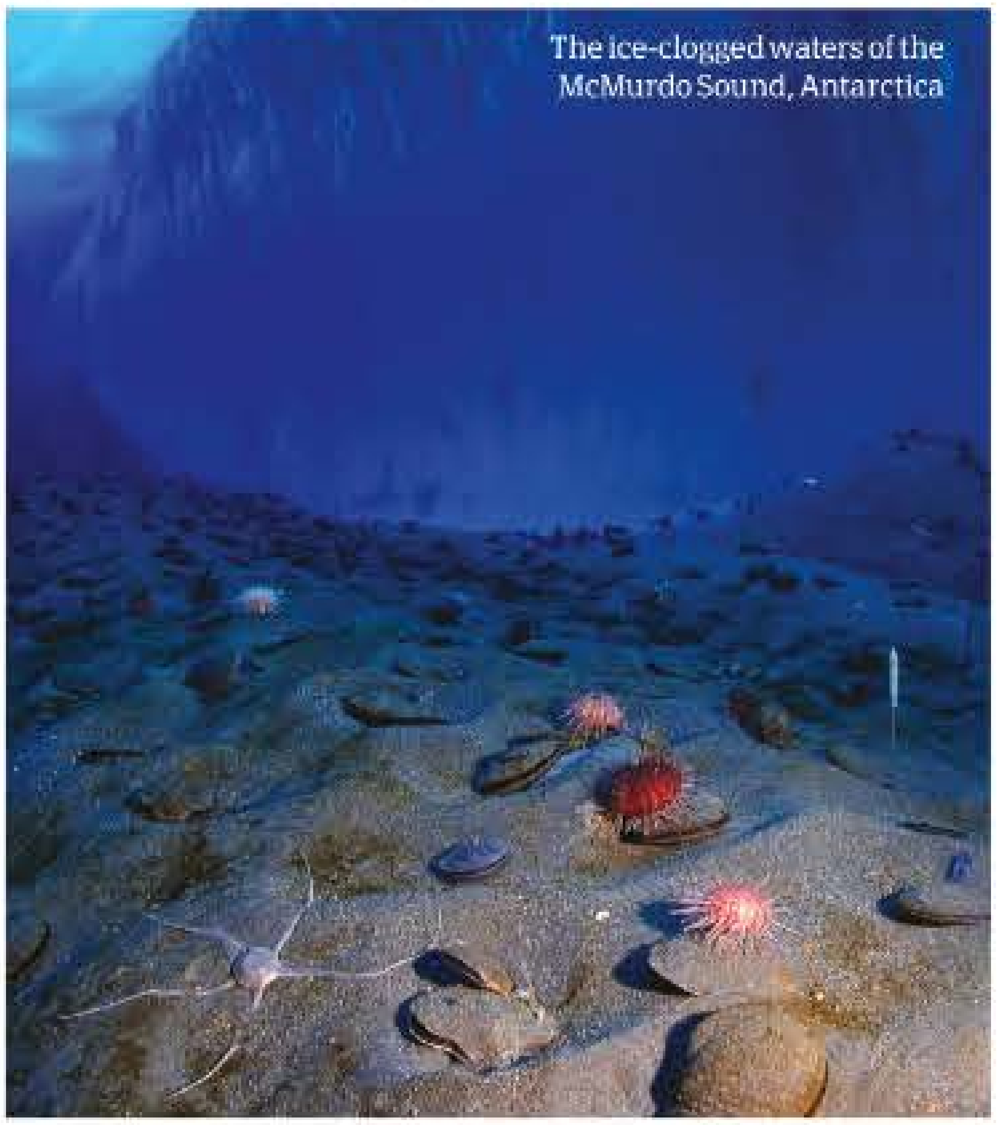
Ross Ice Shelf
The Ross Ice Shelf is the world's largest ice shelf and covers 510,680km (317,322mi) squared, roughly the area of France. It's about 1km (0.6mi) thick in places.

water with the alkalinity of extra-strength laundry detergent.

Despite the harsh conditions and the lack of soil, animals and plants survive on ice-free parts of Antarctica. In the windswept Dry Valleys, lichens, fungi and algae live in cracks in the rocks. Towards the coast, on islands and the peninsula, mosses are fed on by tiny insects, including microscopic worms, mites and midges. Some insects called springtails use their own natural antifreeze, so they can survive temperatures of less than -25°C (-13°F). There are even two species of flowering plants to spot.

In contrast, the Southern Ocean surrounding Antarctica is among the richest oceans in the world. The annual growth and melting of sea ice dredges nutrients from the ocean depths, resulting in phytoplankton. A single litre of water can contain more than a million of these tiny plants. The phytoplankton are eaten by krill – tiny shrimp-like creatures that are the powerhouse of Antarctica's ecosystem and feed most of its predators, including seals, fish, whales and penguins. They form dense swarms, with more than 10,000 krill in each cubic metre of water. Some swarms extend for miles and can even be seen from space. Alarming recent studies show that krill stocks have fallen by 80% since the Seventies, probably due to global warming.

All of Antarctica's species are adapted to the extreme cold. Seals and whales have a thick layer of blubber for insulation and penguins have dense, waterproof plumage to protect them from salty, surface water at a frigid -1.8 °C (29°F). Some species of fish have antifreeze in their blood. Antarctic icefish have transparent blood and absorb oxygen through their skin.


The ice-clogged waters of the McMurdo Sound, Antarctica

The most common birds are penguins. Of the 17 species of Antarctic penguins, only two live on the continent itself. One is the world's largest penguin, the emperor penguin, which grows to 115cm (4ft) tall. Being large helps the penguin to keep warm. Emperor penguins breed on Antarctica's sea ice during the cold, dark winter, enduring blizzards and low temperatures. The male penguins keep their eggs warm by balancing them on their feet for up to nine weeks, while the female goes fishing at sea. During this fasting period, these super-dads huddle in groups of up to 5,000 penguins to keep warm, losing 45% of their body weight.

During the summer, around 4,400 scientists and support staff live on Antarctica, carrying out experiments. Some are drilling to extract cylinders of ice more than three kilometres (two miles) long, to provide a record of the climate covering perhaps the last 740,000 years. The ice contains ancient air bubbles and compressed layers of snow. Scientists are also drilling into underground lakes like Lake Vostok, which may contain water and microbes isolated from the outside world for a million years.

Astrophysicists also benefit from Antarctica's clean, dry air. IceCube is an Antarctica-based experiment that tracks neutrinos, ghostly particles created by exploding stars. Another experiment is attempting to detect faint light from the Big Bang that created our universe. Scientists are also studying the feeding habits of Adélie penguins, using scales to check their weights on their favourite walking routes.

Lake Vanda has the clearest ice in the world (as transparent as distilled water), and it's possible to see straight down for many metres

Mount Erebus
Mount Erebus is among Earth's largest active volcanoes. Heat escaping the volcano melts the snow above into caves. The steam released freezes instantly into chimneys up to 18m (60ft) high.

East Antarctic ice sheet
The East Antarctic ice sheet is Earth's largest. It is more than 3km (2mi) thick in places and mainly flat, vast, featureless polar desert swept by icy winds.

Dry Valleys
The McMurdo Dry Valleys are Antarctica's largest ice-free area and resemble Martian landscapes. They contain mummified seal remains, salty lakes and a river that flows inland in the summer.

Lake Vostok
Lake Vostok is the biggest of 145 lakes buried beneath Antarctica's ice. Discovered in 1996, it's the largest geographic feature discovered on Earth in the last 100 years.

Transantarctic Mountains
The Transantarctic Mountains are among the world's biggest mountain ranges and divide Antarctica in two. They are 3,300km (2,051mi) long, with treeless peaks over 3km (2mi) high.

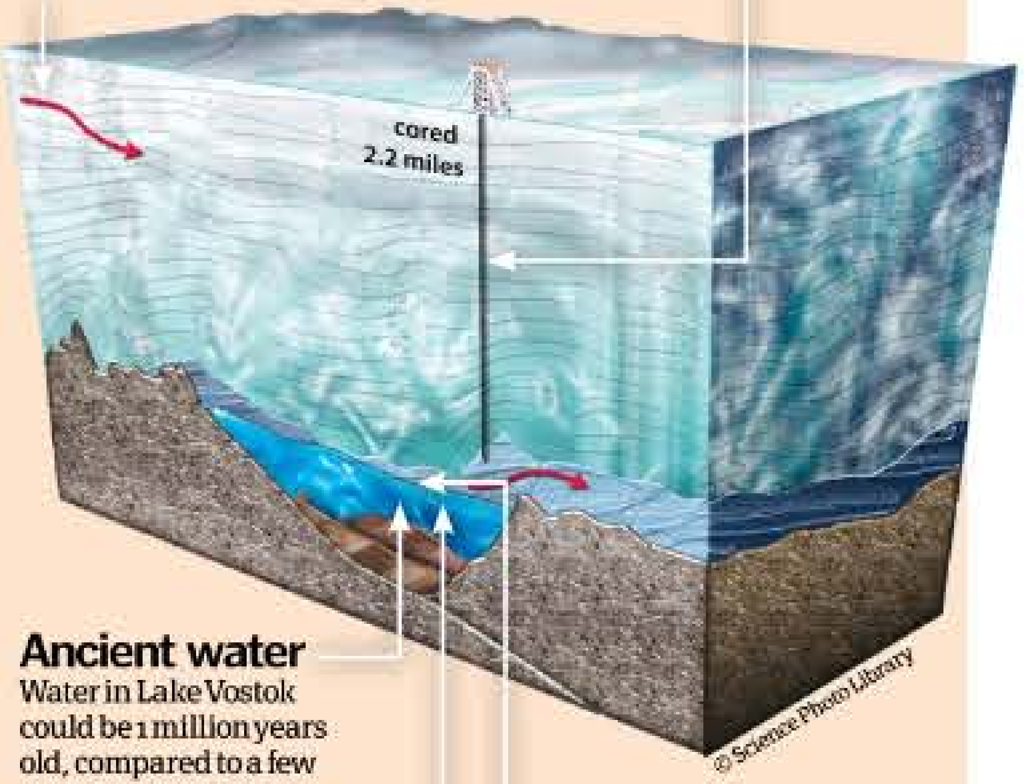
© DK Images

Lake Vostok – an alien world

Discover the largest lake beneath Antarctica's surface

Ice flow
The mass of ice on top of the lake takes thousands of years to creep from shore to shore.

Life search
Russian researchers are drilling to the lake water through 4km (2.5mi) of ice to search for life.



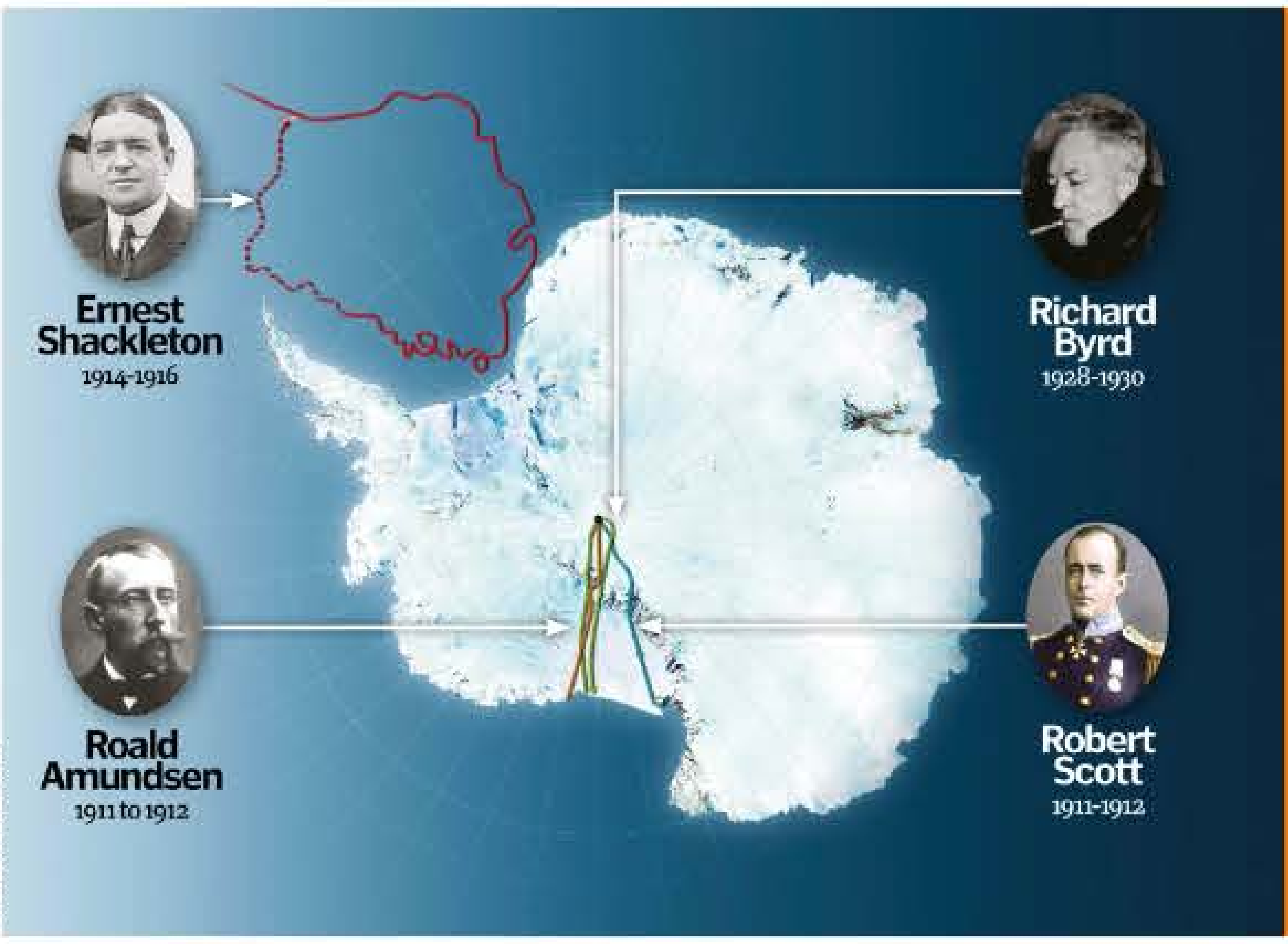
© Science Photo Library

Ancient water
Water in Lake Vostok could be 1 million years old, compared to a few years for a typical lake.

Extreme living
Bacteria may live in Lake Vostok despite the perpetual darkness, icy water and enormous pressures.

Sloping lake surface
The lake surface slopes downwards because the ice is about 400m (1,312ft) thicker at one end than the other.

An over-sea ice seismic survey in progress



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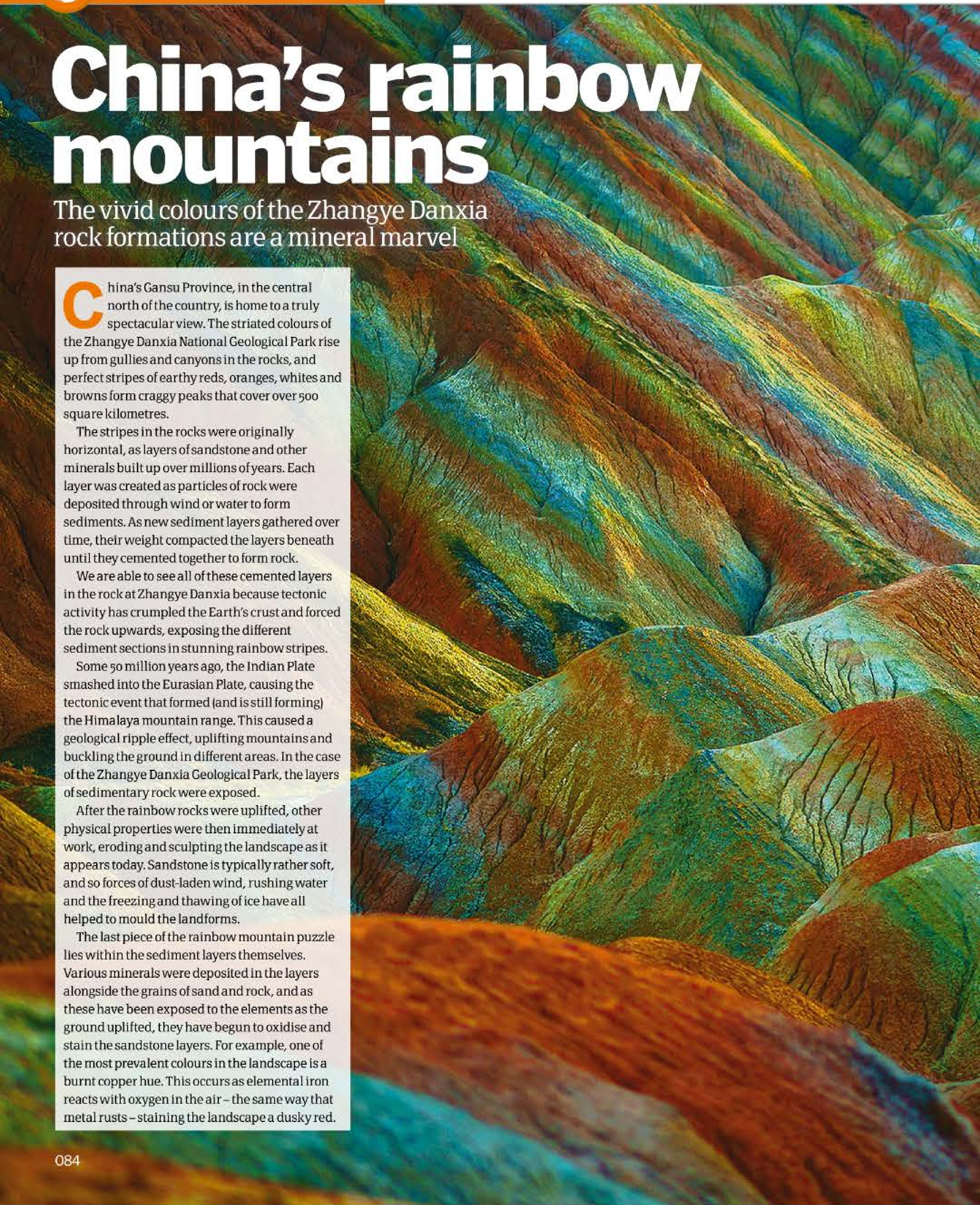
Early expeditions across Antarctica

By the late 19th century, Antarctica was Earth's last unexplored continent. The South Pole was the remotest place. The Pole was reached in December 1911 by Norwegian explorer Roald Amundsen who pioneered a new route. Amundsen's party raced the British expedition led by Robert Scott who arrived 33 days afterwards, having battled harsh weather and terrain. Scott's dispirited party died from starvation and exposure on the return journey. In 1914, Ernest Shackleton tried crossing Antarctica, but his ship 'Endurance' was crushed by winter ice. All his crew survived almost two years camping on the ice, until Shackleton led an epic 1,300 kilometres (808 miles) trip in a small boat to seek help. From 1928 onwards US explorer Richard Byrd led five expeditions to Antarctica, claiming vast territories for the USA. In November 1929, he flew over the South Pole. Today, the Pole is no longer uncharted territory – it even has its own post office!

China's rainbow mountains

The vivid colours of the Zhangye Danxia rock formations are a mineral marvel



China's Gansu Province, in the central north of the country, is home to a truly spectacular view. The striated colours of the Zhangye Danxia National Geological Park rise up from gullies and canyons in the rocks, and perfect stripes of earthy reds, oranges, whites and browns form craggy peaks that cover over 500 square kilometres.

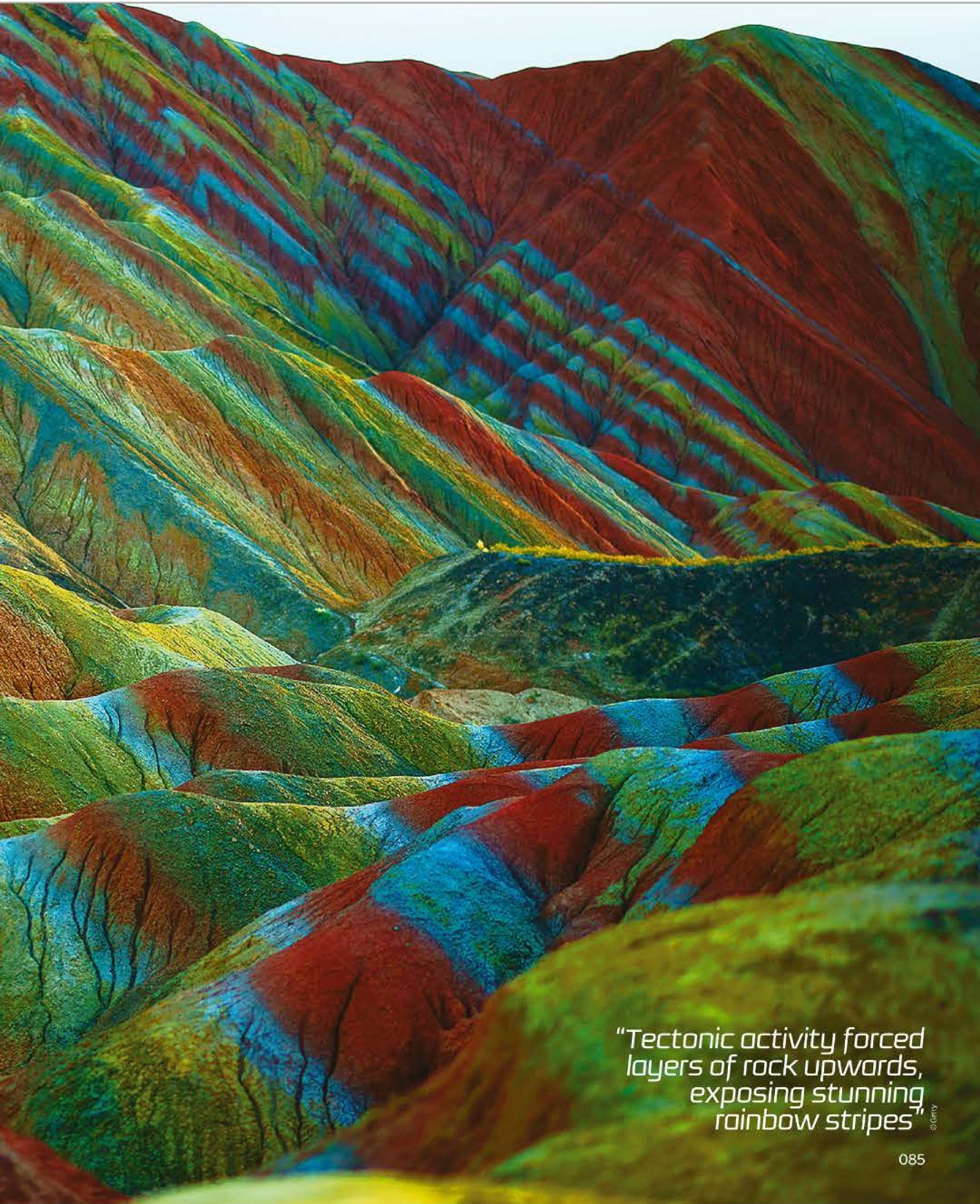
The stripes in the rocks were originally horizontal, as layers of sandstone and other minerals built up over millions of years. Each layer was created as particles of rock were deposited through wind or water to form sediments. As new sediment layers gathered over time, their weight compacted the layers beneath until they cemented together to form rock.

We are able to see all of these cemented layers in the rock at Zhangye Danxia because tectonic activity has crumpled the Earth's crust and forced the rock upwards, exposing the different sediment sections in stunning rainbow stripes.

Some 50 million years ago, the Indian Plate smashed into the Eurasian Plate, causing the tectonic event that formed (and is still forming) the Himalaya mountain range. This caused a geological ripple effect, uplifting mountains and buckling the ground in different areas. In the case of the Zhangye Danxia Geological Park, the layers of sedimentary rock were exposed.

After the rainbow rocks were uplifted, other physical properties were then immediately at work, eroding and sculpting the landscape as it appears today. Sandstone is typically rather soft, and so forces of dust-laden wind, rushing water and the freezing and thawing of ice have all helped to mould the landforms.

The last piece of the rainbow mountain puzzle lies within the sediment layers themselves. Various minerals were deposited in the layers alongside the grains of sand and rock, and as these have been exposed to the elements as the ground uplifted, they have begun to oxidise and stain the sandstone layers. For example, one of the most prevalent colours in the landscape is a burnt copper hue. This occurs as elemental iron reacts with oxygen in the air – the same way that metal rusts – staining the landscape a dusky red.



"Tectonic activity forced layers of rock upwards, exposing stunning rainbow stripes"

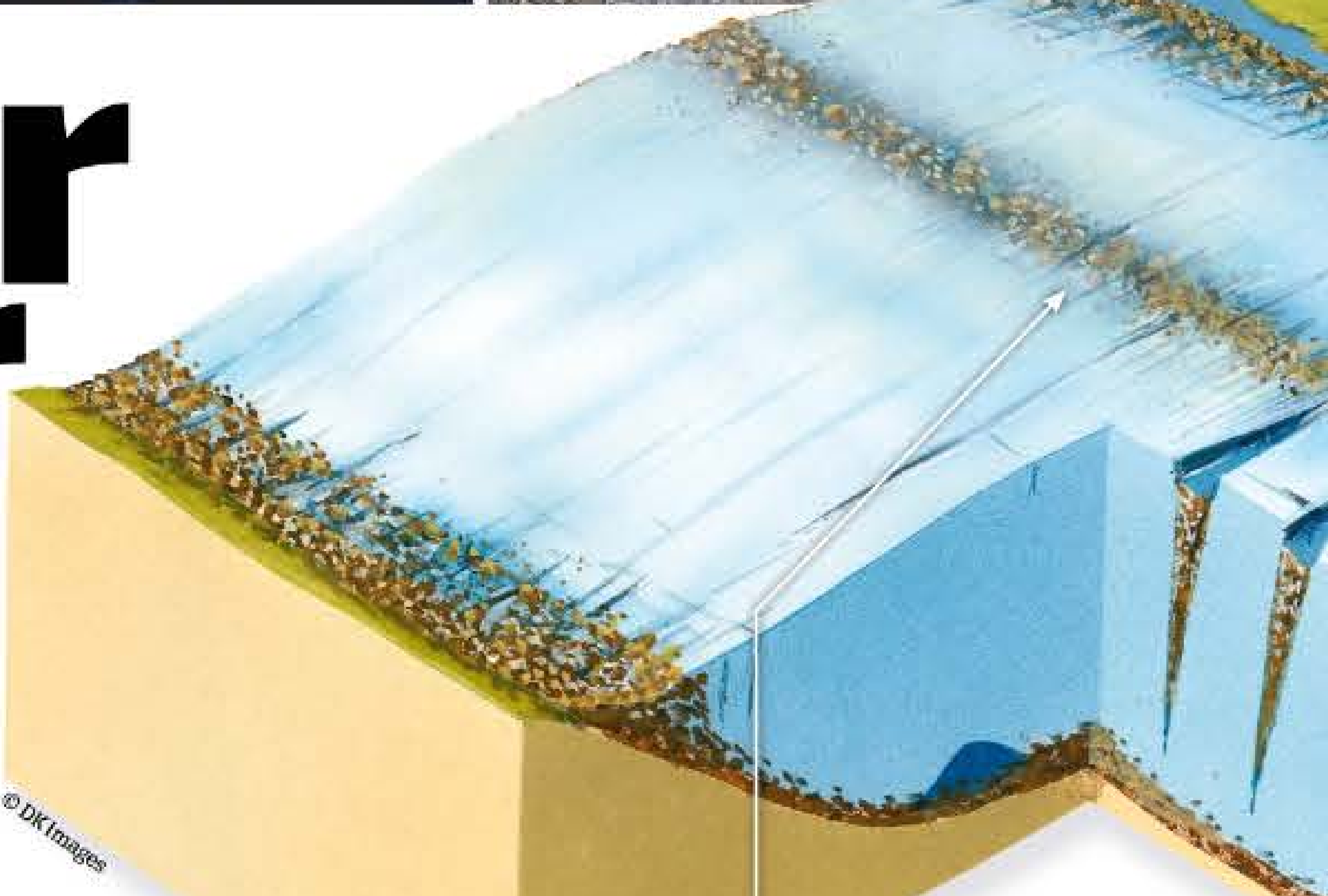
© Getty

Glaciers in Wrangell St Elias National Park, Alaska

Briksdalsbreen, one of the best-known arms of the Jostedalsbreen glacier

Glacier power

Discover the awesome Earth-shaping power of gigantic rivers of ice



© DK Images

8. Snout

The end of the glacier is called its snout, perhaps because it looks like a curved nose. The snout changes position as the glacier retreats and advances.

2. Medial moraine

A medial moraine is a debris ridge or mound found in the centre of a valley, formed when two tributary glaciers join and their lateral moraines merge.

Glaciers are huge rivers or sheets of ice, which have sculpted mountain ranges and carved iconic peaks like the pyramid-shaped Matterhorn in the Swiss Alps. The secret of this awesome landscape-shaping power is erosion, the process of wearing away and transporting solid rock. Glacial erosion involves two main mechanisms: abrasion and plucking. As glaciers flow downhill, they use debris that's frozen into the ice to 'sandpaper' exposed rock, leaving grooves called 'striations'. This is the process of abrasion. Plucking, however, is where glaciers freeze onto rock and tear away loose fragments as they pull away.

Today glaciers are confined to high altitudes and latitudes, but during the ice ages glaciers advanced into valleys that are now free of ice. Britain, for example, was covered by ice as far south as the Bristol Channel.

You can spot landforms created by ancient ice. Cirques are armchair-shaped hollows on mountainsides, often containing lakes called 'tarns'. They're also the birthplaces of ancient glaciers. During cold periods, ice accumulates in shady rock hollows, deepening them to form cirques. When two cirques form back-to-back, they leave a knife-edge ridge called an 'arête'. Pyramidal peaks are created when three or more cirques form. Eventually the cirque glacier spills from the hollow and flows downhill as a valley glacier. This glacier erodes the valley into a U-shape, with steep cliffs called 'truncated spurs'. When the glacier melts, tributary valleys are left hanging high above the valley floor.

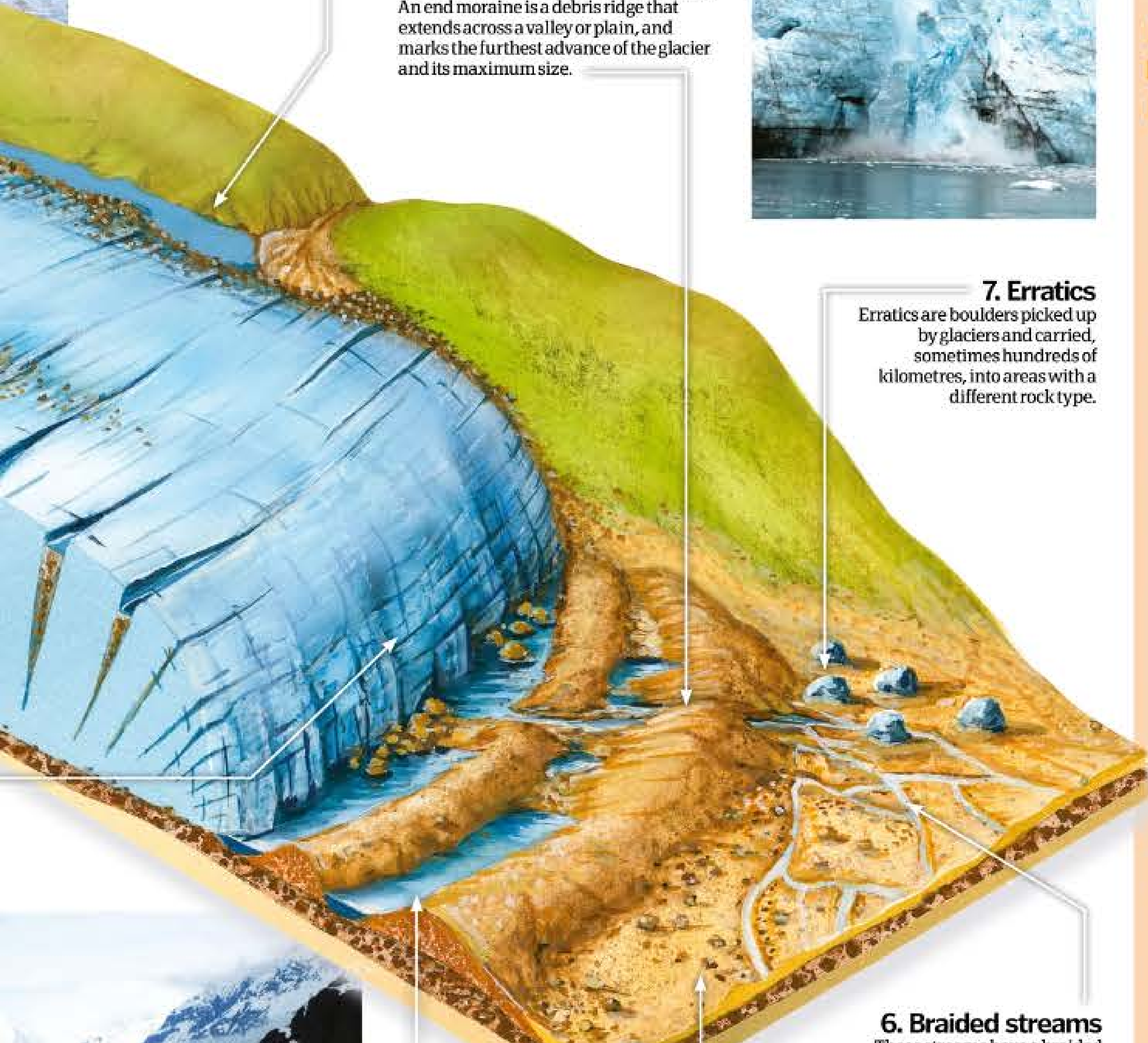
Hard rock outcrops in the valley were smoothed into mounds orientated in the direction of ice movement. Rock drumlins are shaped like whalebacks, adopting a smooth, convex shape. Roche moutonnée have a smooth upstream side, and a jagged downstream side formed by plucking. Where valley rocks varied in strength, the ice cut hollows into the softer rock, which filled with glacial lakes known as paternoster lakes.

Modern-day glaciers are found where it's cold enough for ice to persist all year round

Spotter's guide to lowland glaciers

When you stand at the bottom – or snout – of a valley glacier, you can see landforms made of debris dumped by the ice. The debris was eroded further up the valley and transported downhill, as if on a conveyor belt. Meltwater rushing under the glacier sculpts the debris heaps.

The snout is the place in the valley where the glacier melts completely. This changes over time. If the glacier shrinks, it leaves a debris trail behind. Should it grow again, it collects and bulldozes this debris. To understand why the snout moves up and downhill, you need to see glaciers as systems controlled by temperature and snowfall. On cold mountain peaks, snow accumulates faster than the glacier melts. As ice flows into warmer lowlands, melting begins to exceed accumulation. The snout advances or retreats depending on whether inputs of snow exceed ice loss from the system by melting.



1. Lateral moraine

Lateral moraines are made from rocks that have fallen off the valley sides after being shattered by frost. When the glacier melts, the moraine forms a ridge along the valley side.

3. Terminal or end moraine

An end moraine is a debris ridge that extends across a valley or plain, and marks the furthest advance of the glacier and its maximum size.

7. Erratics

Erratics are boulders picked up by glaciers and carried, sometimes hundreds of kilometres, into areas with a different rock type.

6. Braided streams

These streams have a braided shape because their channel becomes choked with coarse debris, picked up when the stream gained power during periods of fast glacier melt.

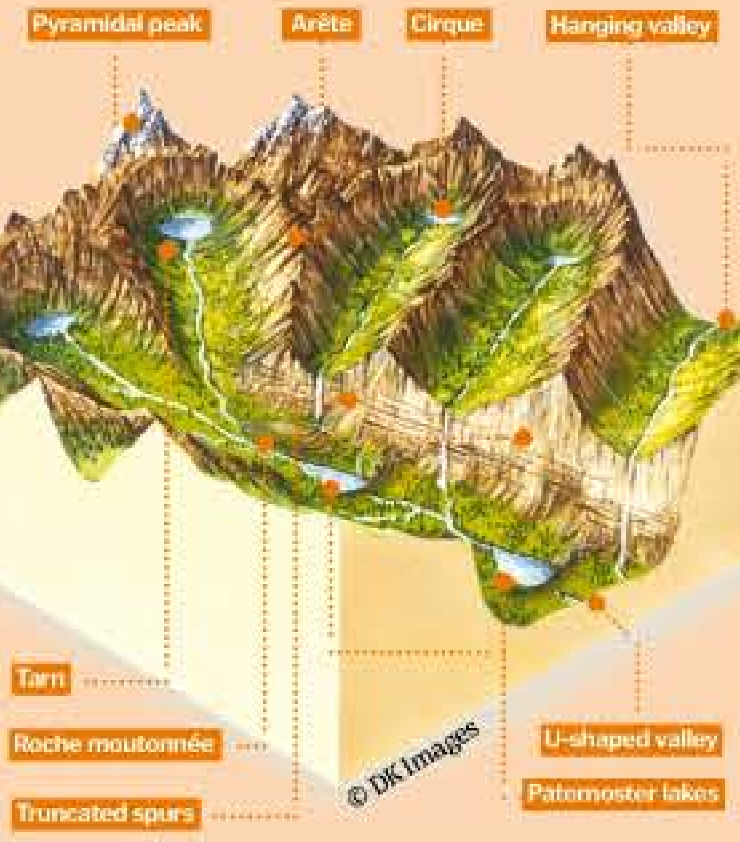
5. Outwash plain

Outwash plains are made of gravel, sand and clay dropped by streams of meltwater that rush from the glacier during the summer, or when ice melts.

4. Recessional moraine

A recessional moraine is left when a glacier stops retreating long enough for a mound of debris to form at the snout.

Inside an ice-carved valley



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An aerial shot of a glacier

How does a glacier move?

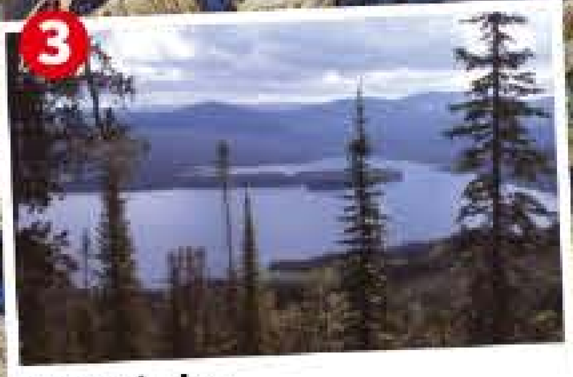
Glaciers can only move, erode and transport debris if they have a wet bottom. Polar glaciers are frozen to the bedrock all year round and typically move around 1.5 metres (5 feet) per year, as ice crystals slide under gravity. In temperate climes like the European Alps, however, glaciers can slide downhill at 10-100 metres (30-330 feet) per year, due to the fact that meltwater forming under the glacier during mild summers acts as a lubricant.

If meltwater accumulates under a glacier, the ice can race forwards at up to 300 metres (990 feet) per day. During the fastest recorded surge, the Kutiah Glacier in Pakistan sped more than 12 kilometres (7.5 miles) in three months.

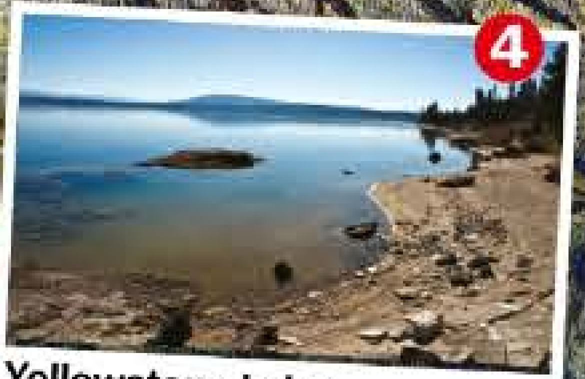
Wonders of YELLOWSTONE

Jackson Lake

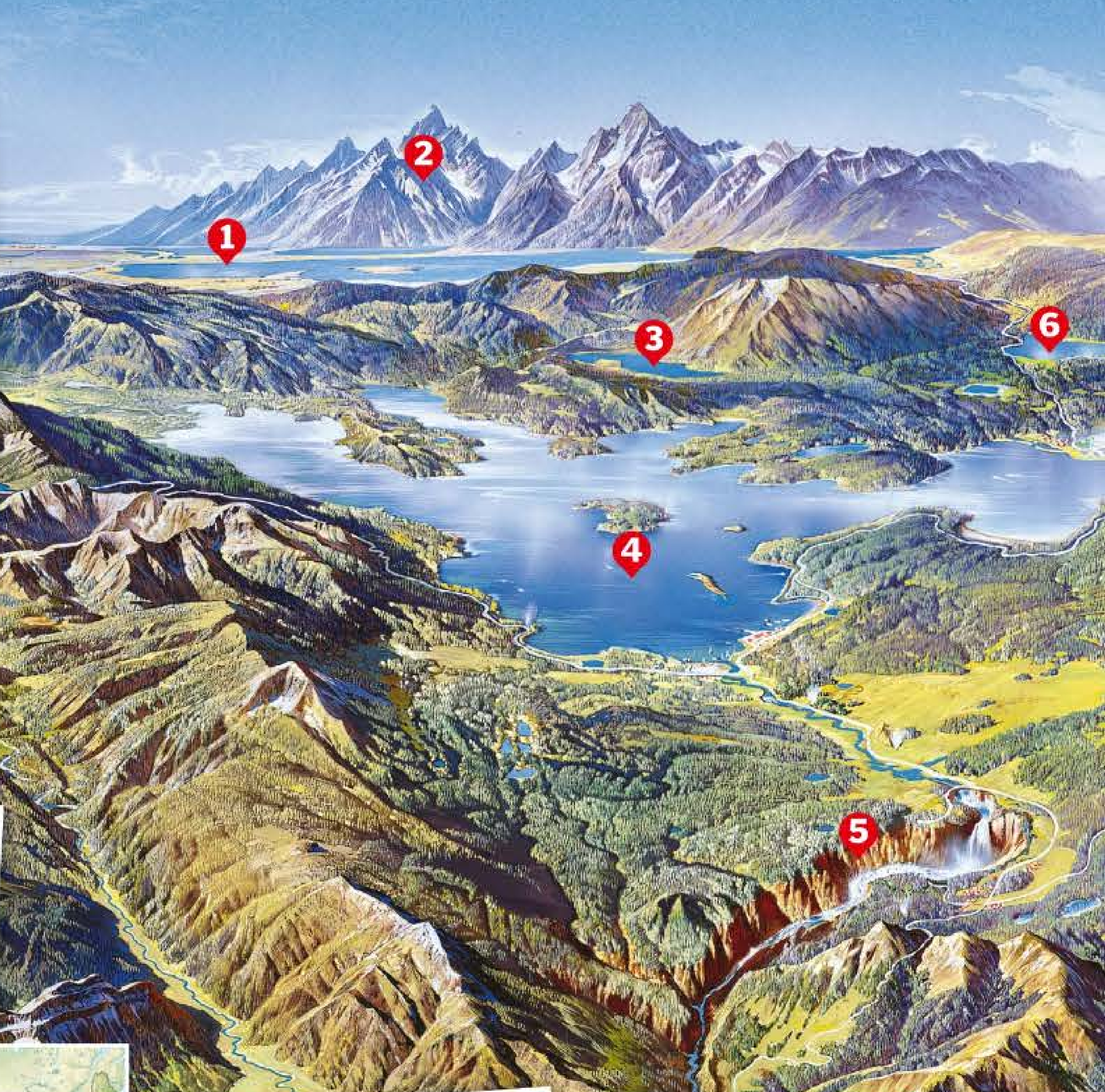
Grand Teton

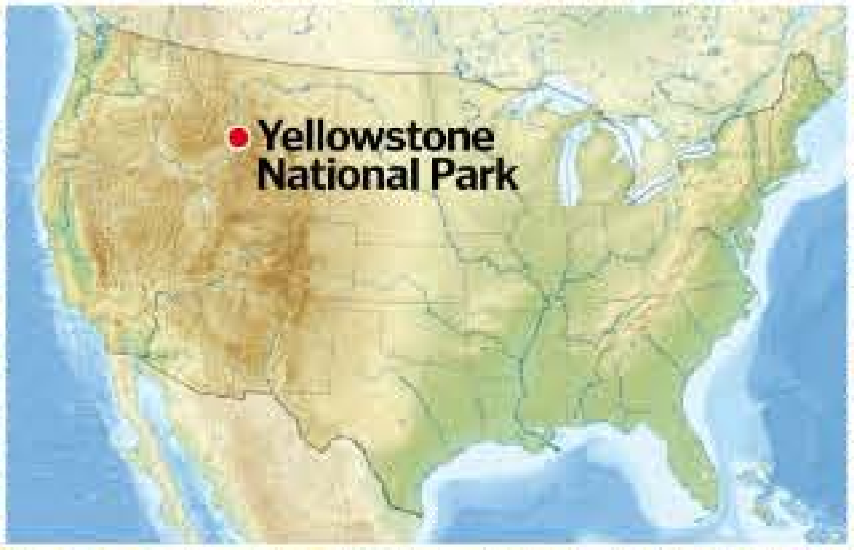


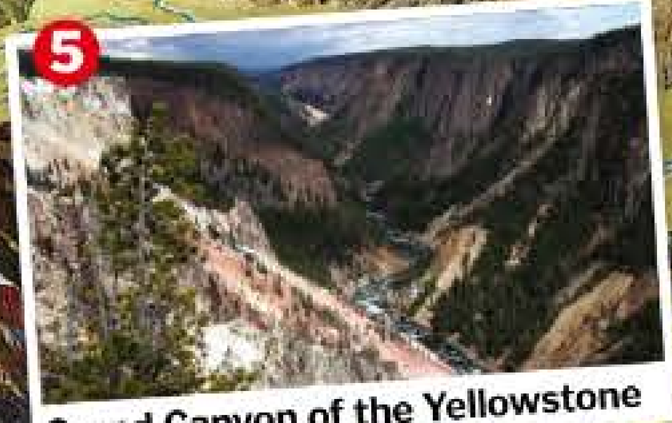
Heart Lake



Yellowstone Lake







Grand Canyon of the Yellowstone

Lewis Lake

DID YOU KNOW? *There are more people injured by bison than grizzly bears each year in Yellowstone*

PARK

Wild beasts, 30-metre high geysers and a supervolcano that could destroy America

Welcome to Yellowstone Park – America's, and the world's, very first national park. Its vast swath of 9,000 square kilometres (3,500 square miles) of protected land, which spans the borders of Wyoming, Montana and Idaho, could house all five boroughs of New York City ten times over, and attracts over 3 million visitors each year.

Its world-renowned scenery includes soaring peaks, plunging canyons, lush forests, rushing rivers, brilliant lakes, rolling meadows, thundering waterfalls, shimmering hot springs and gushing geysers. Amid all this visual poetry lives a rich assortment of wildlife, including wolves, bears, bison and elk.

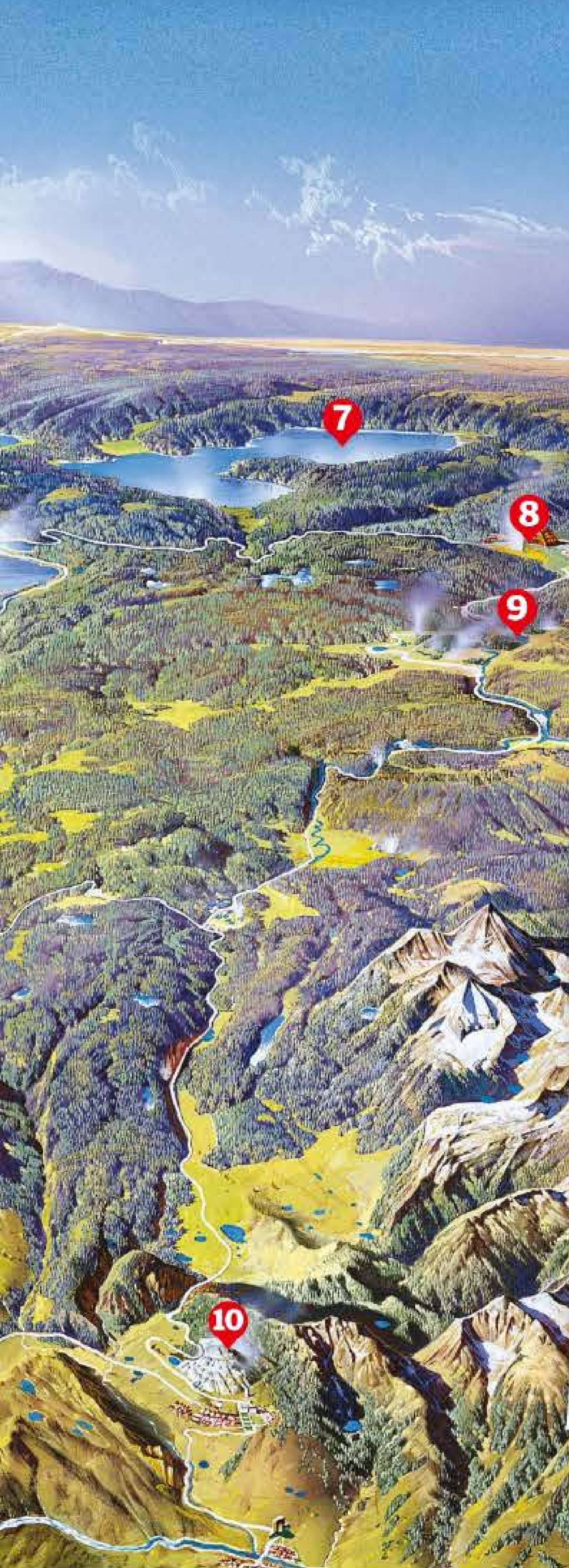
Yellowstone National Park was established by US Congress in 1872, soon after the first Europeans arrived in the American West, but archaeological records show that people have been in Yellowstone for over 11,000 years. Many tribes have lived on and passed through the land now occupied by the park, including the famous Native American Sheepeaters.

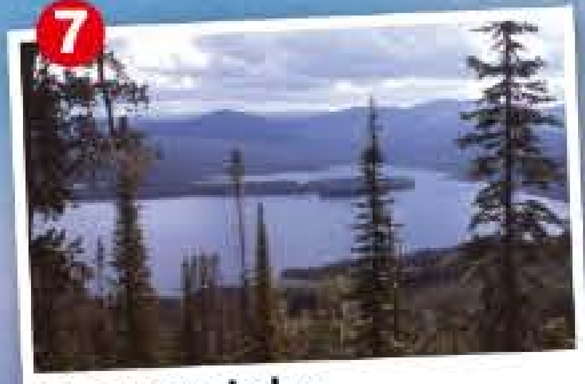
The park lies at the heart of the Greater Yellowstone Ecosystem, which at over 80,000 square kilometres (30,000 square miles) is one of the largest nearly intact temperate-zone ecosystems on Earth. It preserves a staggering variety of terrestrial, aquatic and microbial life, making it a truly invaluable resource for scientists who are conducting various studies, ranging from landscape-level changes right down to some of the tiniest microscopic organisms imaginable.

Yellowstone was set aside as the world's first national park primarily because of its extraordinary geology and hydrothermal wonders. The park contains around half of all the hydrothermal features on Earth – over 10,000 of them – including hot springs, mud pots, fumaroles and the world's greatest concentration of geysers. The most famous of these, Old Faithful, is a perennial crowd pleaser that reliably erupts almost once every hour.

Yellowstone's hydrothermal features are fuelled by volcanic activity deep within the Earth. Just a few miles underneath the park, partially molten rock churns and seethes. The area has seen three gargantuan volcanic eruptions and at least 30 smaller ones over the last two million years, and the park and its immediate surroundings typically experience between 1,000 and 3,000 earthquakes each year, with several large enough to be felt by visitors.

Visitors, wildlife, and the park's pristine landscapes are managed and protected by a team of rangers – 780 work during the peak summer season and a core 355 are permanent year-round employees. As you might expect, competition to become a park ranger at Yellowstone is fierce. Can you imagine a better "office" to go to each day?





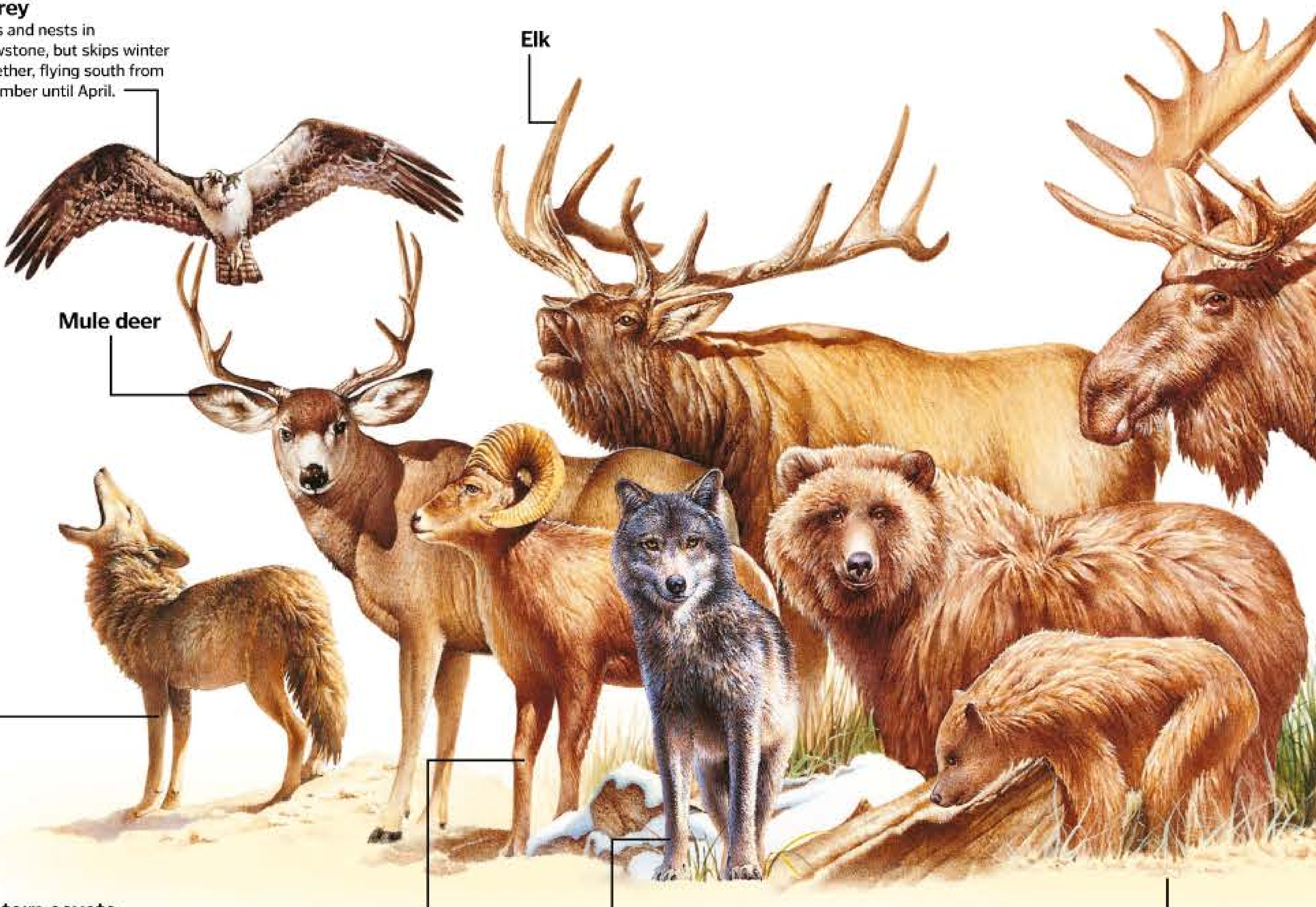
Shoshone Lake

'Old Faithful' Geyser

Grand Prismatic Spring

Mammoth Hot Springs

© National Park Service/Heinrich Berann



Osprey
Mates and nests in Yellowstone, but skips winter altogether, flying south from September until April.

Elk

Mule deer

Western coyote
Forms hunting packs during the colder months, joining forces to find food more effectively.

Rocky Mountain bighorn sheep
Descends to lower elevation south-facing slopes where there is less snowfall and more sunlight which keeps vegetation accessible.

Grey wolf
Grows a thick, insulating winter coat consisting of warm fuzzy underfur protected from moisture by thick waterproof guard hairs.

Grizzly bear (and cub)
Hibernates from December to May, dropping its body temperature and heart rate to conserve energy.

Animals of Yellowstone

As well as breathtaking scenery, Yellowstone is home to a staggering diversity of wildlife. The region sustains one of the largest communities of free roaming large animals seen anywhere on Earth, and contains the most powerful mega fauna in the contiguous US. Following the re-introduction of grey wolves in 1995, today's Yellowstone boasts almost the full complement of animal species that inhabited the park when it was first explored over a century ago.

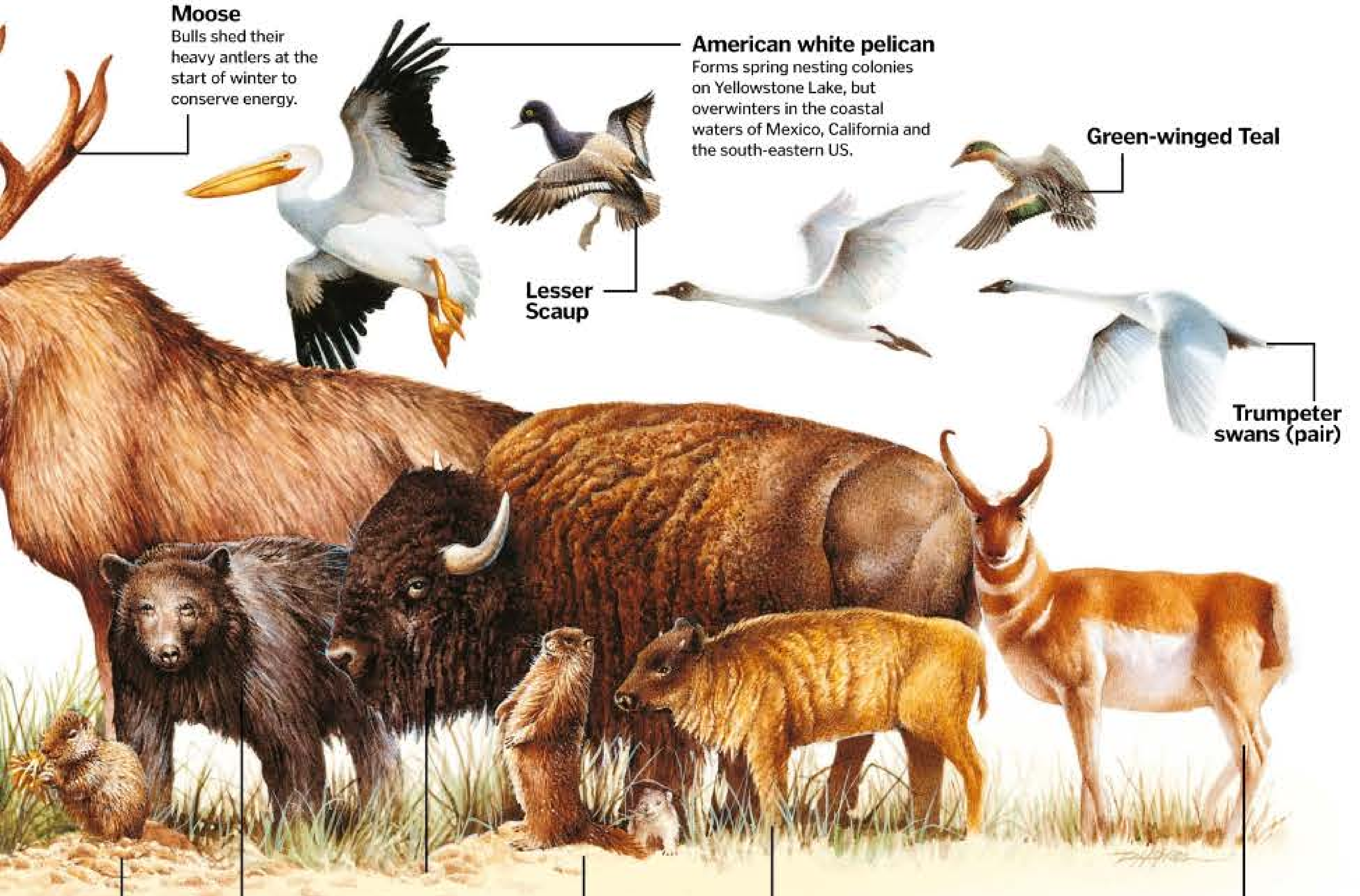
As well as wolves, some of the major attractions for park visitors are the two types of bears – grizzlies and black bears – bison, wild horses and America's national bird, the bald eagle. Among the animal species are 67 mammals, nearly 300 birds, 16 fish, four amphibians and six reptiles, which can be found within the park's boundaries. The variety and abundance of wildlife is due, in part, to the collection of specialist habitats it encompasses. The animals are also protected by law; only park rangers may fire guns, although visitors can obtain fishing permits.

But that isn't to say that life in Yellowstone is a walk in the park for its inhabitants. They must endure cold harsh winters, with temperatures at or below freezing from November through to March and snowfall heavy enough to cause the main roads to be closed for months on end. Each species has its own way of coping – from the moose's specially hinged joints, which they can swing over the snow rather than having to plough through it, to the bison's tendency to graze and find warmth near hydrothermal areas.

The entire Yellowstone ecosystem exists as a delicate balance between predators, prey, and their habitat – itself governed by climate fluctuations, forest fires, invasive species and volcanic activity. The way the park is managed today reflects shifting attitudes and new understanding about this balance. For example, wolves, once considered too great a threat to other species, are now recognised as linchpins in the health and stability of the overall ecosystem. Forest fires were once viewed purely in terms of the death and destruction they cause, but today controlled burns are recognised as a critical step in the natural cycle of regeneration and renewal.

Yellowstone is the only place in the contiguous US where bison have roamed continuously since prehistoric times

DID YOU KNOW? *During the 1988 "summer of fire" 36 per cent of the park was affected by wildfires*



Moose
Bulls shed their heavy antlers at the start of winter to conserve energy.

American white pelican
Forms spring nesting colonies on Yellowstone Lake, but overwinters in the coastal waters of Mexico, California and the south-eastern US.

Lesser Scaup

Green-winged Teal

Trumpeter swans (pair)

Uinta ground squirrel

Black bear

Yellowstone bison (and calf)
Uses its giant head as a snowplough to clear deep snow and find food.

Yellow-bellied marmot
Hibernates for up to eight months of the year, surviving entirely on stored fat.

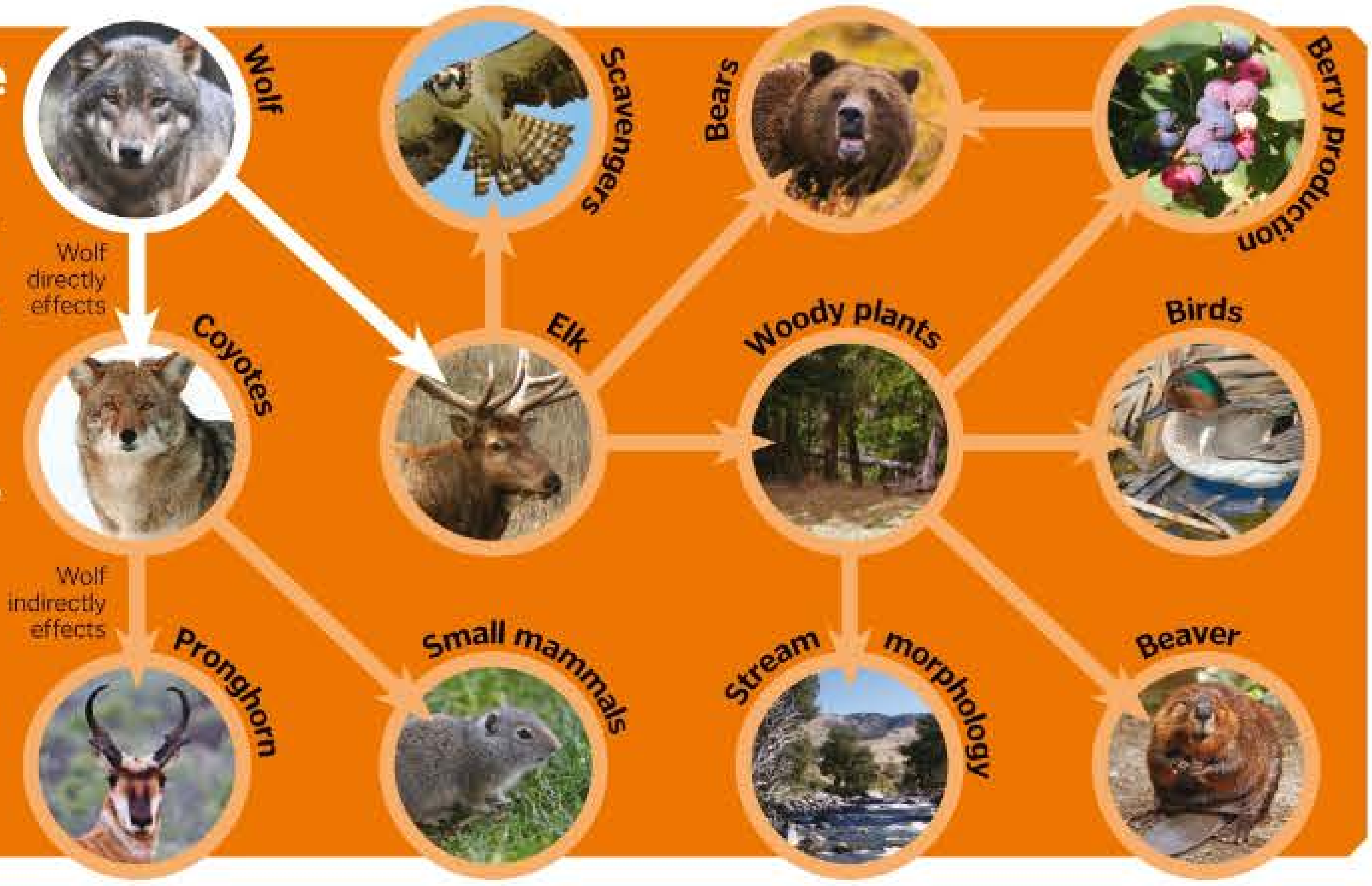
Pika
Spends summer gathering vegetation for winter food, which it builds into vigorously defended "haystacks".

Pronghorn

How wolves balance the Yellowstone ecosystem

An icon of the wilderness, the grey wolf once thrived in Yellowstone before it became systematically shot, trapped and poisoned until it was finally eradicated from the park in 1926. But without the wolves the entire ecosystem went into free-fall; the deer population exploded and grazed almost all the vegetation bare, causing a cascade of knock-on effects.

In 1995, 14 wolves were reintroduced to the park. Where the deer avoided the wolves, woody vegetation flourished and beavers – whose dens are important to otters, fish, reptiles and amphibians – were bolstered. Wolves kept the coyote population in check, which boosted numbers of small mammals. Bears thrived on wolves' discarded carcasses and the new proliferation of berries. Even rivers were affected with their banks strengthened by improved plant growth, erosion slowed and they meandered less.



© National Park Service/ Robert Hynes; Thinkstock

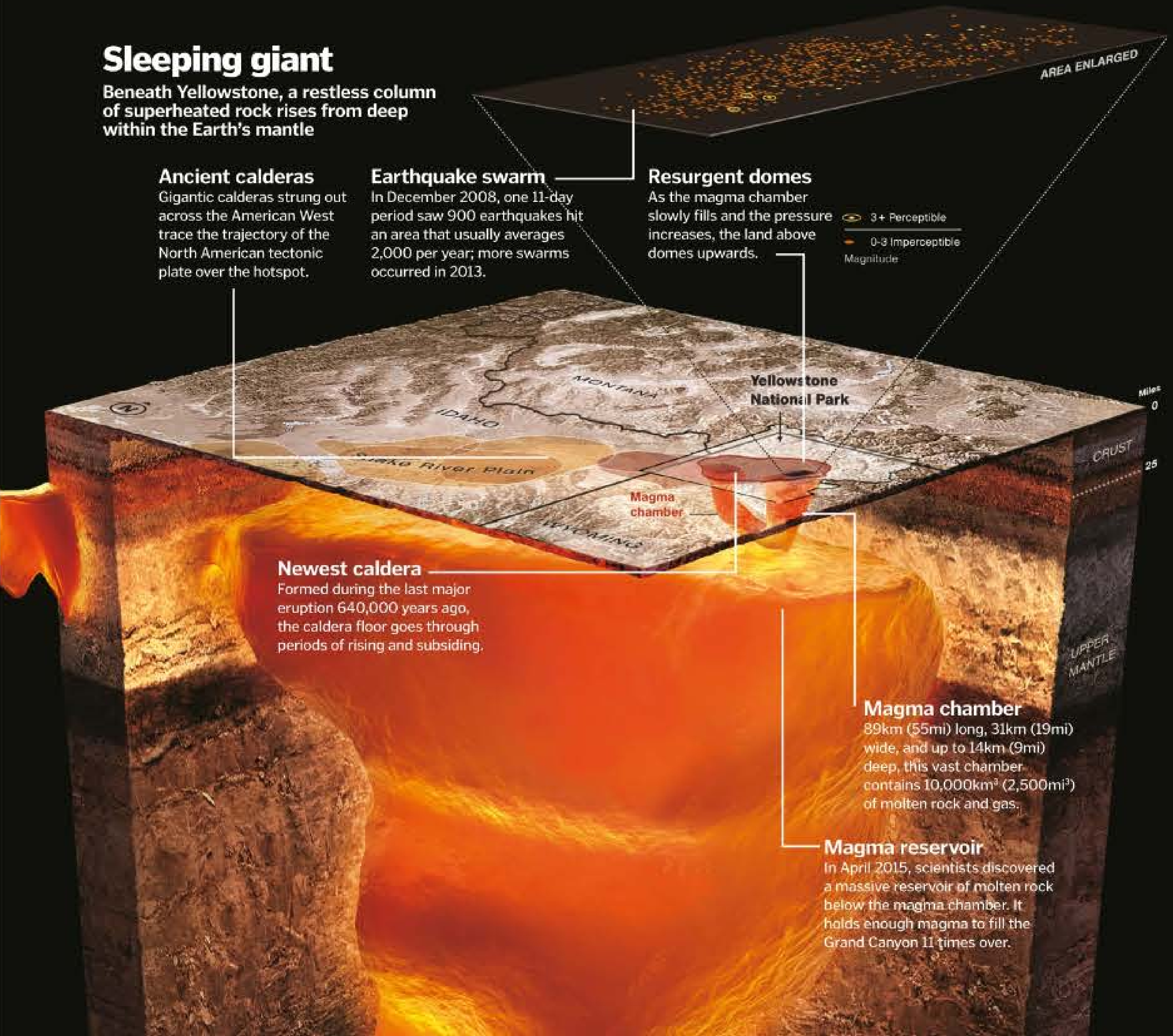
What lies beneath...?

Yellowstone's natural serenity belies its violent volcanic underbelly. In fact, one third of the park's area lies within the gigantic caldera of a colossal supervolcano. These types of volcanoes are defined by their ability to eject more than 1,000 cubic kilometres (240 cubic miles) of material – making them at least a thousand times larger than the 1980 Mount Saint Helens eruption, the deadliest and most destructive volcanic eruption ever recorded in US history.

Yellowstone's supervolcano is powered by an immense geological hotspot, which fuels a growing magma chamber directly underneath the park. Three massive eruptions have occurred within Yellowstone – 2.1 million, 1.3 million, and 640,000 years ago respectively – a regular pattern that leads many experts to believe a globally catastrophic eruption is long overdue.

Sleeping giant

Beneath Yellowstone, a restless column of superheated rock rises from deep within the Earth's mantle



Ancient calderas
Gigantic calderas strung out across the American West trace the trajectory of the North American tectonic plate over the hotspot.

Earthquake swarm
In December 2008, one 11-day period saw 900 earthquakes hit an area that usually averages 2,000 per year; more swarms occurred in 2013.

Resurgent domes
As the magma chamber slowly fills and the pressure increases, the land above domes upwards.

Newest caldera
Formed during the last major eruption 640,000 years ago, the caldera floor goes through periods of rising and subsiding.

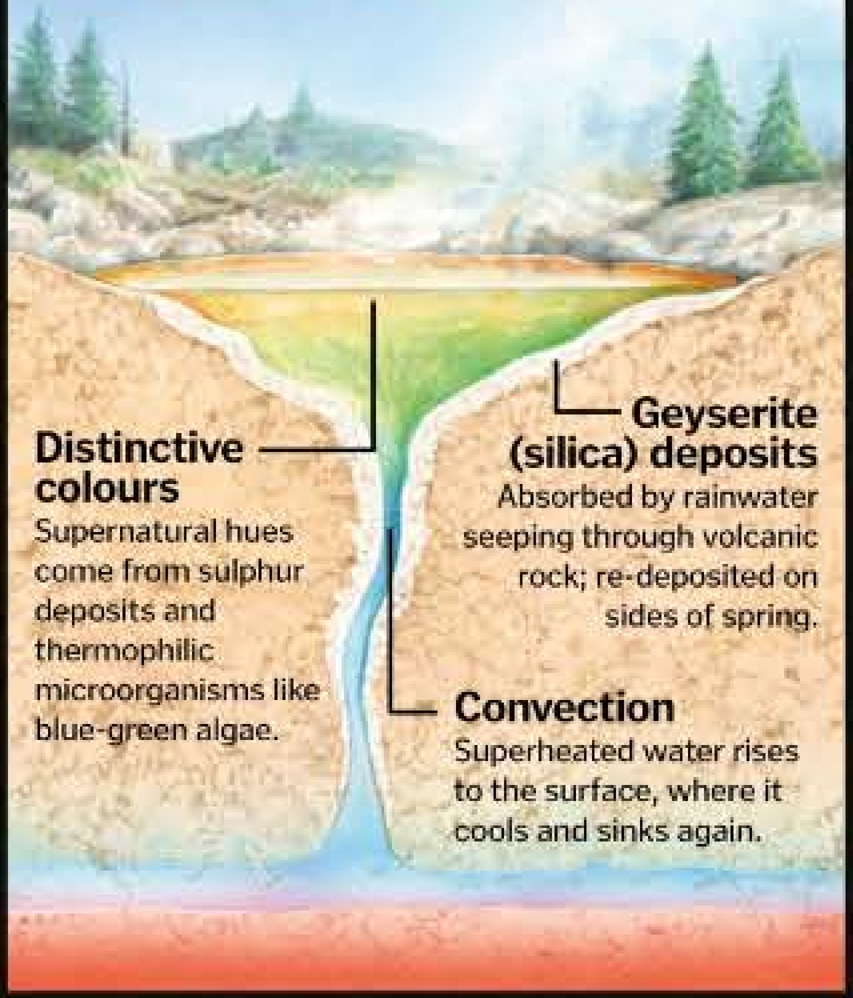
Magma chamber
89km (55mi) long, 31km (19mi) wide, and up to 14km (9mi) deep, this vast chamber contains 10,000km³ (2,500mi³) of molten rock and gas.

Magma reservoir
In April 2015, scientists discovered a massive reservoir of molten rock below the magma chamber. It holds enough magma to fill the Grand Canyon 11 times over.

Guide to Yellowstone's hydrothermal features

Hot springs

The most common type of thermal feature in Yellowstone, formed when rain and snow seeps through the underlying bedrock and becomes superheated from the energy radiated by partially molten rock that lie a few miles below the surface.



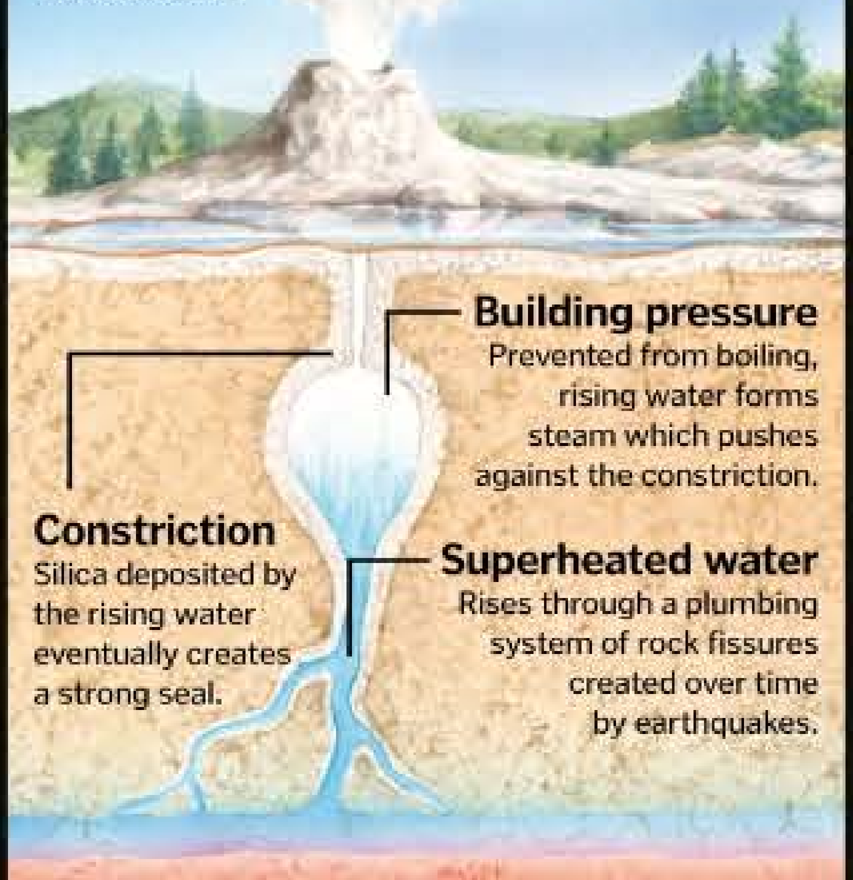
Distinctive colours
Supernatural hues come from sulphur deposits and thermophilic microorganisms like blue-green algae.

Geyserite (silica) deposits
Absorbed by rainwater seeping through volcanic rock; re-deposited on sides of spring.

Convection
Superheated water rises to the surface, where it cools and sinks again.

Geysers

A rare kind of hot spring that forms when a plumbing constriction prevents superheated water from circulating freely. Pressure builds as rising water is prevented from boiling, until eventually the geyser blows, spewing huge volumes of steam and water from its vent.

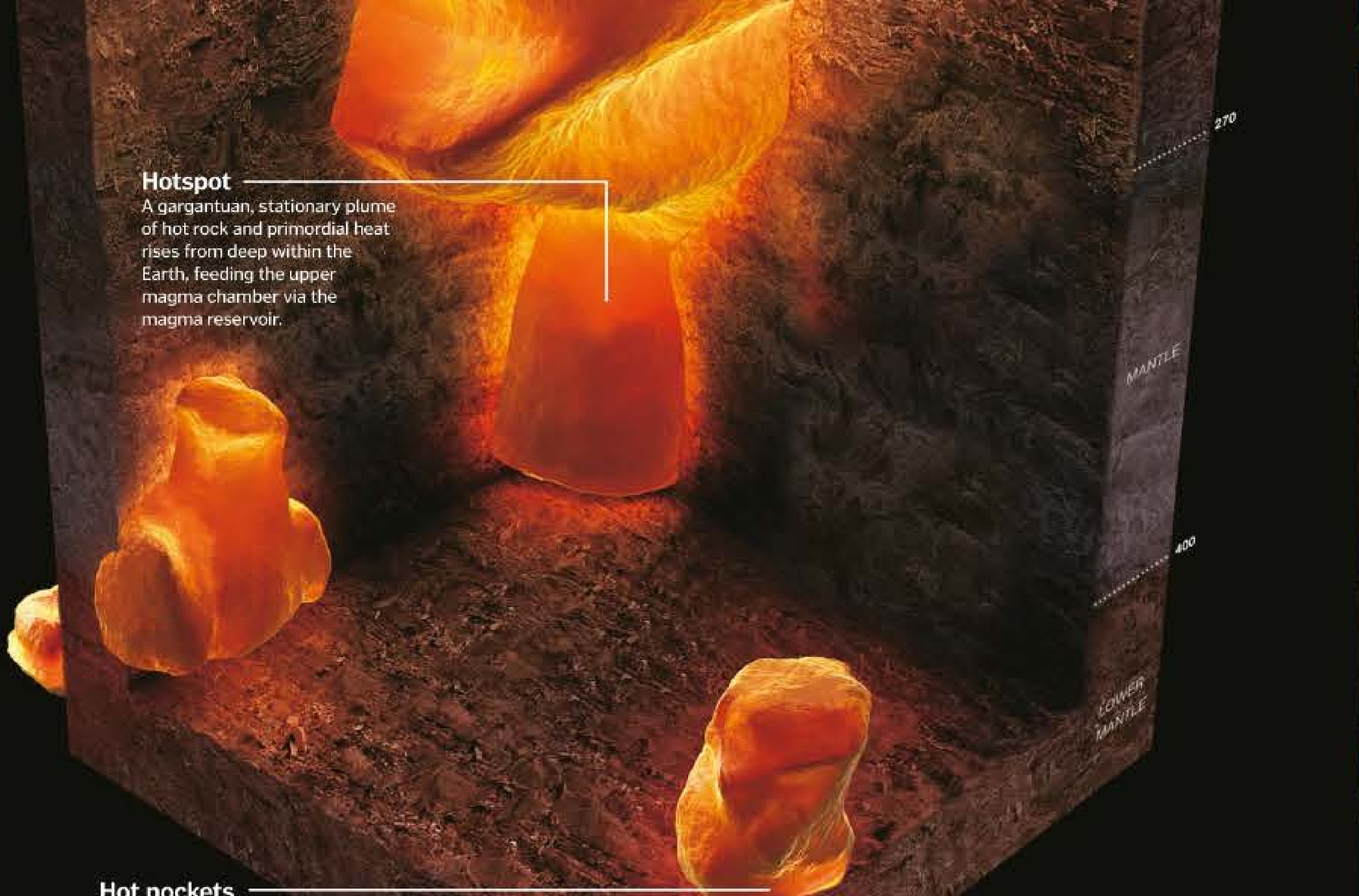


Building pressure
Prevented from boiling, rising water forms steam which pushes against the constriction.

Constriction
Silica deposited by the rising water eventually creates a strong seal.

Superheated water
Rises through a plumbing system of rock fissures created over time by earthquakes.

DID YOU KNOW? *Geyser water's round trip can take hundreds or even thousands of years*



Hotspot
A gargantuan, stationary plume of hot rock and primordial heat rises from deep within the Earth, feeding the upper magma chamber via the magma reservoir.

Hot pockets
Geologists think there may be additional smaller pockets of hot rock associated with the Yellowstone plume.

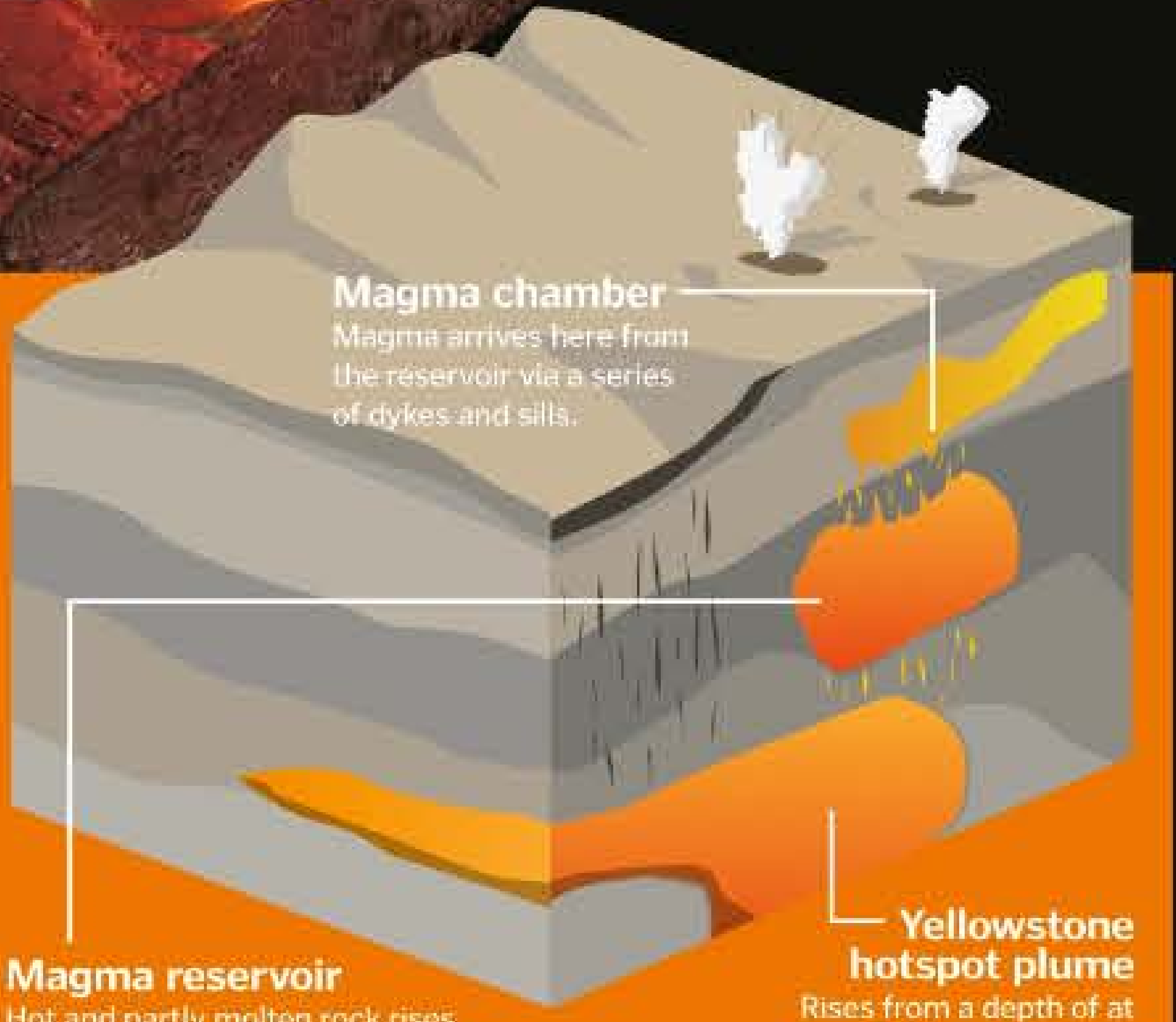
© Corbis

What if Yellowstone blows?

Geologists have never witnessed a supervolcanic eruption, but by looking at remnants of previous cataclysms, mapping the underground bodies of magma and using computer models, they can glean horrifying details about what might happen if Yellowstone blows.

Gas-filled magma would explode from the volcano, raining rocky debris and hot, dense ash – a mix of splintered rock and glass capable of killing people and animals in a most gruesome fashion as they inhale it – across tens of thousands of square kilometres. A high-altitude umbrella cloud would spread out in all directions, blanketing the Rocky Mountains with metres of ash and sending particles across the entire country.

The cloud would temporarily shut down air travel and interfere with electronic communications across North America. Roofs would collapse under the weight of ash; roads, sewers and water supplies would become clogged and unusable, and crops would be smothered. The states of Wyoming, Montana, Idaho, Colorado and Utah would be devastated, perhaps unliveable for several years, and the entire globe would cool by a couple of degrees as gas from the cloud blocks out the Sun, causing climatic effects that could threaten many species with extinction.



Magma chamber
Magma arrives here from the reservoir via a series of dykes and sills.

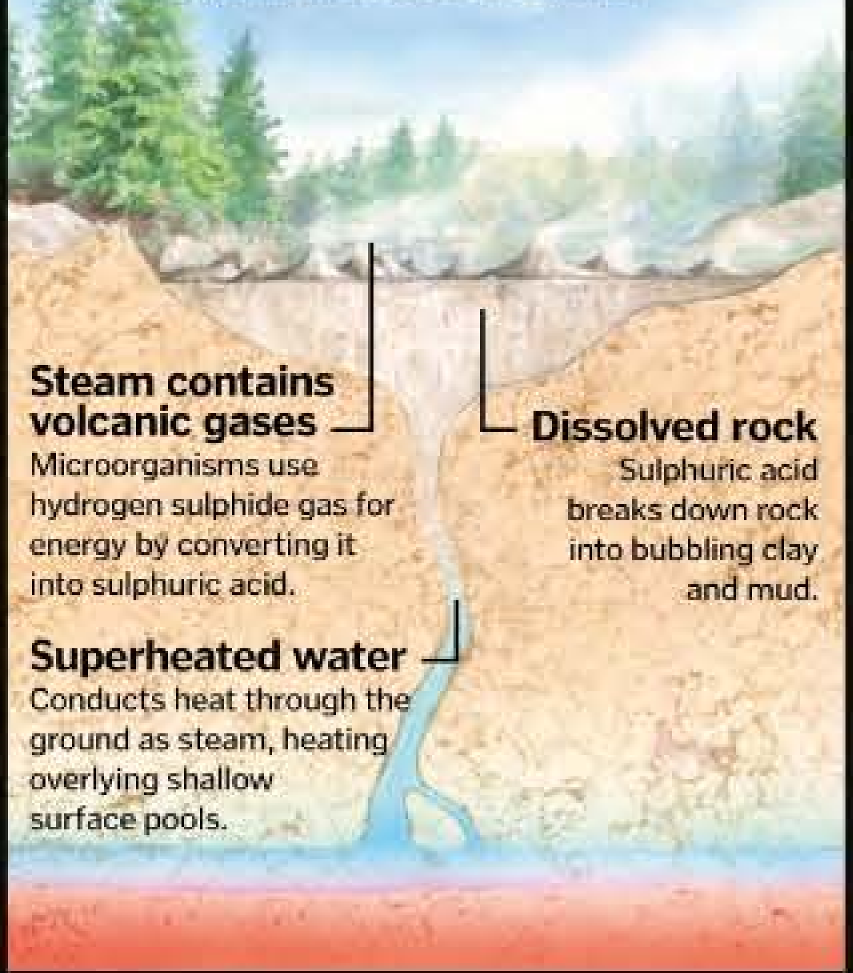
Magma reservoir
Hot and partly molten rock rises through dykes in the uppermost mantle, all collecting in the magma reservoir.

Yellowstone hotspot plume
Rises from a depth of at least 700km (440mi) in the Earth's mantle.

Image by Ed Crooks

Mud pots

Steaming vents of hydrogen sulphide acidify shallow, heated pools of surface water which turns the underlying rock into bubbling blue-grey clay. Minerals in the clay interact with the acids resulting in a shimmering rainbow of coloured deposits.



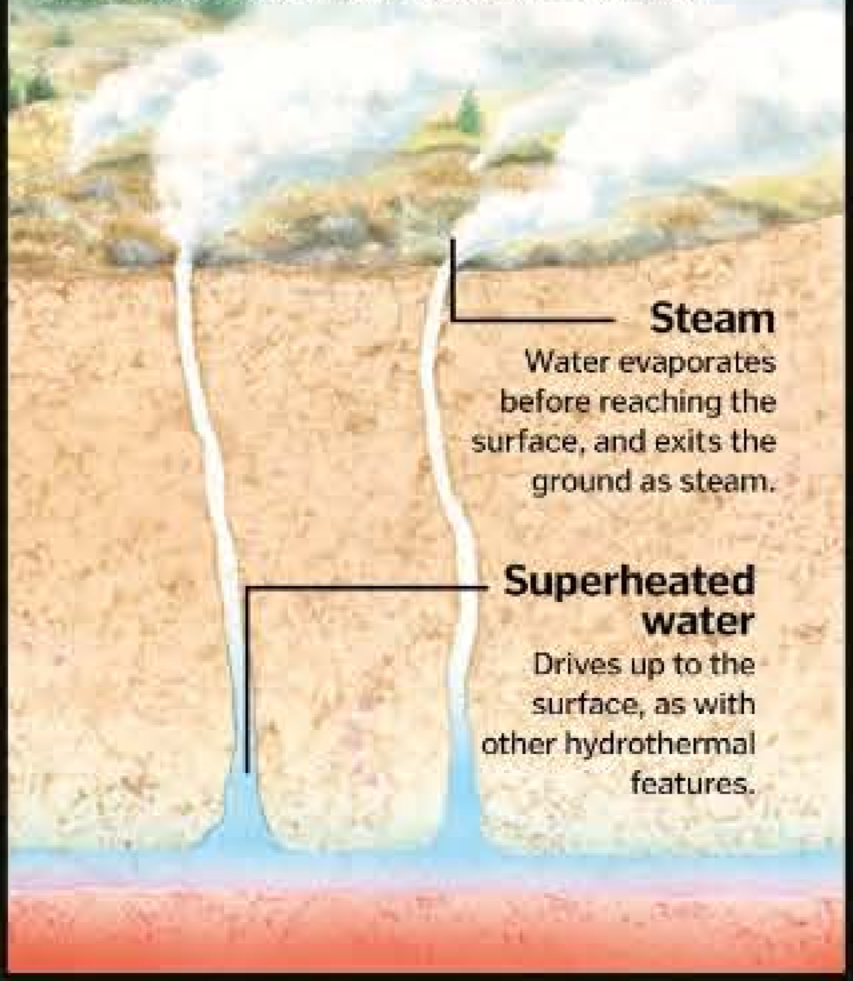
Steam contains volcanic gases
Microorganisms use hydrogen sulphide gas for energy by converting it into sulphuric acid.

Dissolved rock
Sulphuric acid breaks down rock into bubbling clay and mud.

Superheated water
Conducts heat through the ground as steam, heating overlying shallow surface pools.

Fumaroles

Also called a steam vent, these are hydrothermal features with such limited water supplies that it all boils away before reaching the surface. Steam and other gasses emerge from the vent hissing and whistling at temperatures up to 114°C (237°F).



Steam
Water evaporates before reaching the surface, and exits the ground as steam.

Superheated water
Drives up to the surface, as with other hydrothermal features.

Images by Peter Scott/Art Agency

Extreme oceans

Counting down the deepest, deadliest, stormiest and downright most hostile environments on Earth

New South Wales, AustraliaTasman Sea / South Pacific

1 Most shark-infested

Just like *Jaws*, only less cinematic trickery and more lose-a-leg scary

When it comes to shark attacks, there are three species that sit firmly at the top of the food chain: the great white shark, the tiger shark and the bull shark. This is one gnarly trio of hungry fish, who are all keen predators with heightened senses.

The most extreme place on Earth for shark attacks recently is New South Wales coast in Australia and over the last year the country has seen two fatalities, 18 injuries and 29 attacks. It's thought that changing ocean currents are bringing the sharks' prey closer to shore, luring in the ocean beasts alongside the fish.

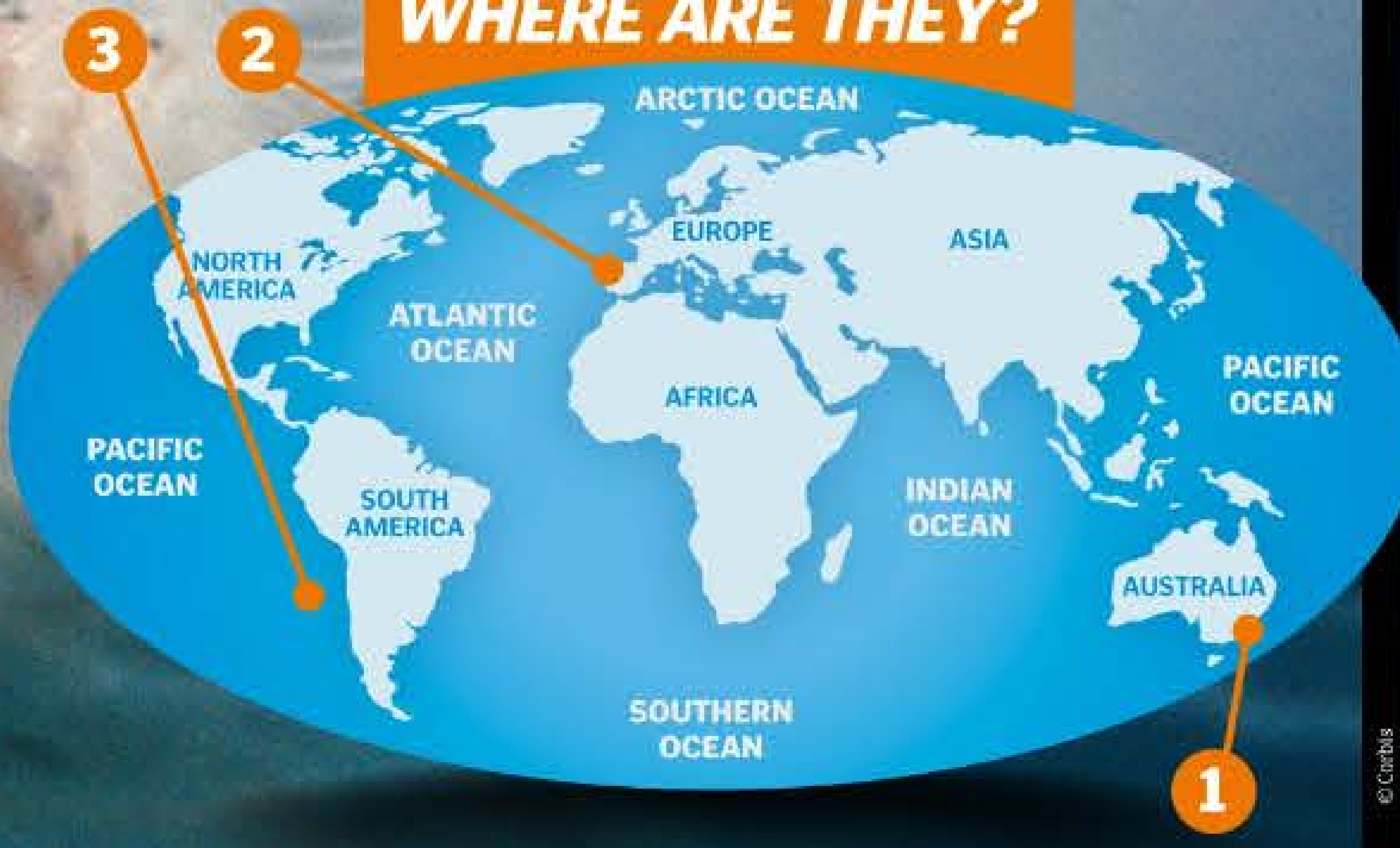
However, before you march out with your torch and pitchfork to chase the sharks from the bays, it's worth bearing in mind that many more people are killed by the water that sharks swim in than by shark attacks themselves. Humans are naturally not a good diet choice for a shark – we are too bony with far too little blubber on us. Sharks need prey that is high in fat, such as seals.

Very often a great white shark will bite a human as a curious nip to find out what they are, rather than in an attempt to feast on them. That said, when you're swimming in an area with a known shark presence, the best advice is to get out of the water. Swim calmly and smoothly, as thrashing around will only draw the shark's attention, and don't ever wear jewellery or anything shiny that could make the shark think that you're a tasty fish covered in scales.

65,000 km
Length of the Mid-Ocean Ridge

31 DAYS
The longest-lasting hurricane

WHERE ARE THEY?



The subterranean canyon off the coast of Nazaré creates incredibly tall waves, making it a popular surfing spot

2 Tallest waves

It's the stuff of every big-wave surfer's dreams: the 30-metre wave. Praia do Norte near the coastal village of Nazaré in Portugal is at one of the most westerly points of Europe, and bears the brunt of the sweeping Atlantic swells. Europe's largest underwater canyon, Nazaré Canyon, lies just offshore, which is a 200-kilometre long ravine that works to combine the energy from waves that have travelled across the Atlantic, currents from the canyon, gusting winds and local tidal forces into colossal waves.

Where: Nazaré, Portugal
Ocean: Atlantic Ocean

3 Fastest growing

Plate tectonics can cause chaos through earthquakes, but they can also cause oceans to grow. The region offshore from Chile and Peru on the East Pacific Rise, where the Pacific plate is pulling away from the Nazca plate, is the site of the fastest seafloor spreading on Earth. This is where two plates pull away from each other, and magma bubbles up from the Earth's core to fill the gap. In this region, up to 16 centimetres of new seafloor is produced per year.

Where: East Pacific Rise
Ocean: Pacific Ocean

© Corbis

4 Extreme storms

Where: Tropical Pacific
Ocean: Pacific Ocean

Is there such a thing as the 'perfect storm'?

Fishermen who make their living out on the waves, battling everything the Pacific throws at them, will tell you that this is one of the cruellest oceans on Earth.

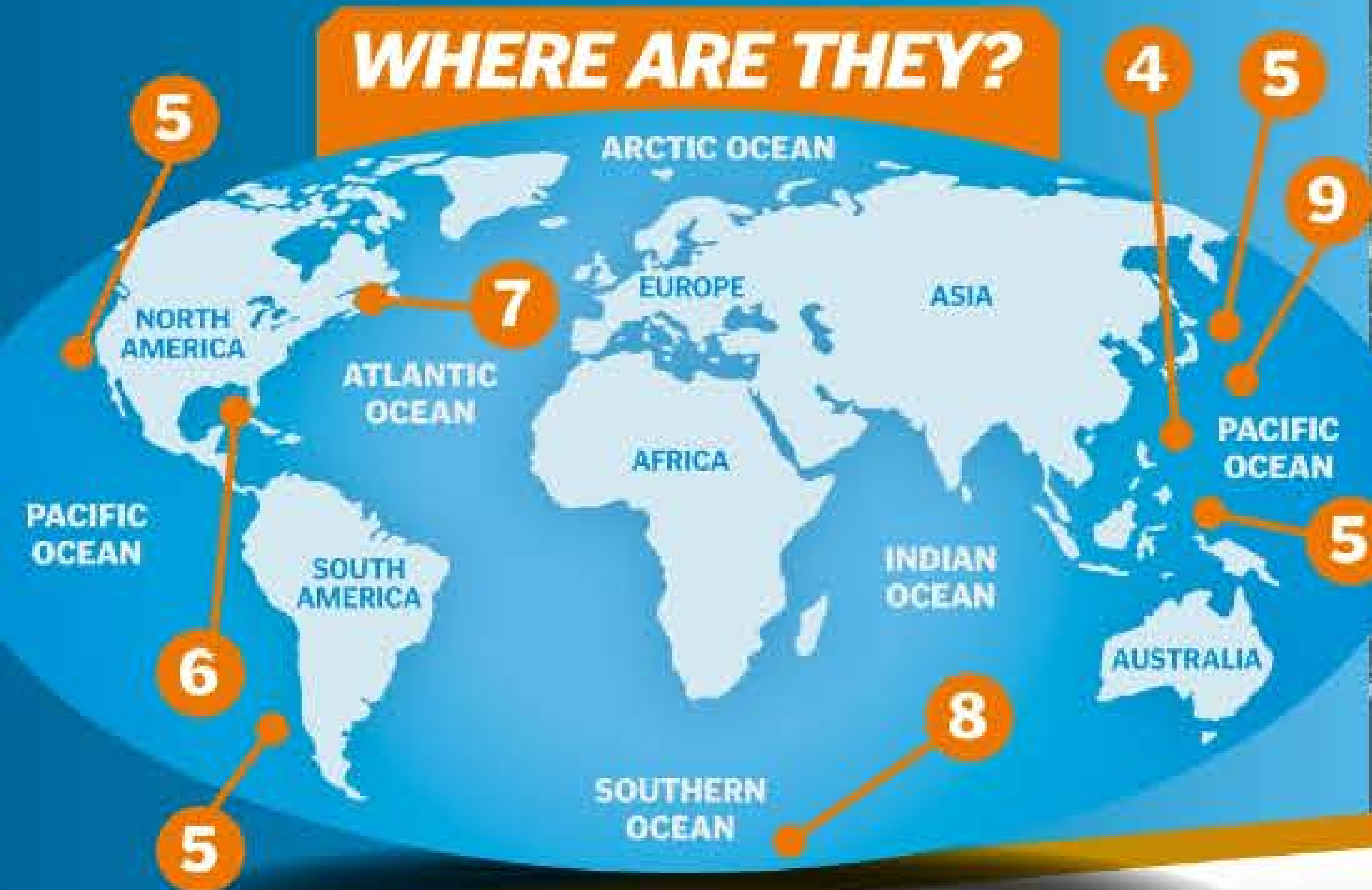
It's the tropical region that whips up this meteorological frenzy and creates the mother of all storms: hurricanes. Fed by very warm, moist air, these weather systems usually form between June and November, and need to reach 120 kilometres per hour or more to be classified as a hurricane, typhoon or cyclone. These three terms describe the same event and just depend on the origin of the storm. In the Atlantic and Northeast Pacific the storms are hurricanes; in the Northwest Pacific they're known as a typhoon; and in the South Pacific and Indian Ocean the weather system is termed a cyclone.

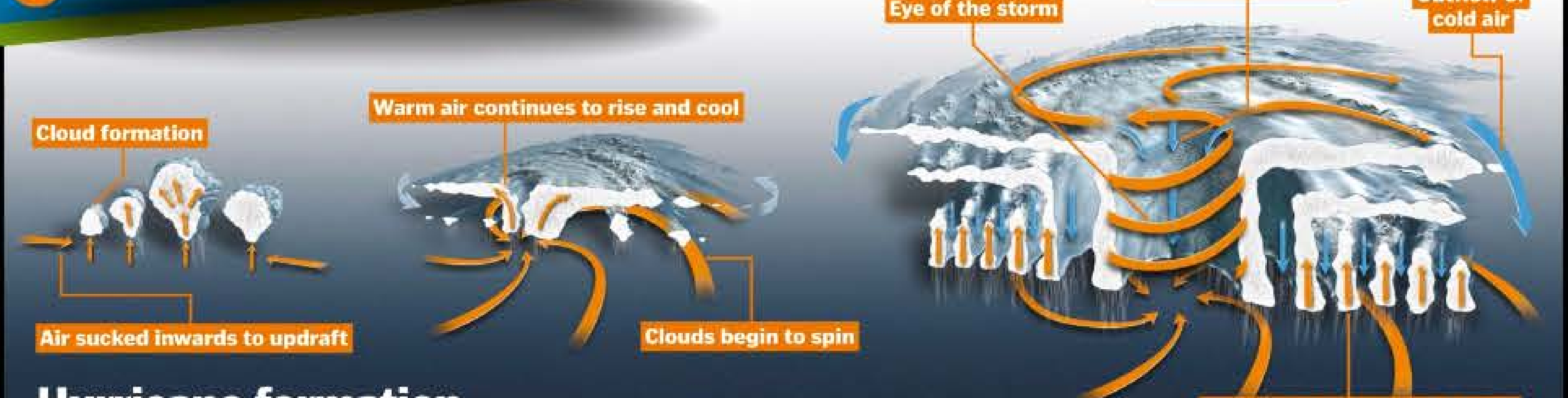
Hurricanes can travel huge distances across oceans, spinning anticlockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere, fed by the warm conditions of the tropics.

A storm name is retired if, like Katrina, it has had catastrophic effects

1.3bn km³
Amount of water (approximate) in the oceans

WHERE ARE THEY?




Eye of the storm
Cool, dry air sinks
Outflow of cold air
Warm air continues to rise and cool
Cloud formation
Air sucked inwards to updraft
Clouds begin to spin
Warm, moist air rises in bands

Hurricane formation

How the vast, swirling storms begin life at sea

1 Cloud formation

Over warm, tropical waters, seawater begins to evaporate. As it rises, it cools to rapidly form clouds. Cooler air from the surrounding area rushes in to replace the warm air, which then warms up and rises again, causing updrafts.

2 Rotation begins

The warm air continues to rise, cool and suck in more air from the surroundings below, gaining energy. As the Earth rotates, the clouds start to spin too. A hurricane is formed once wind speeds reach 120km/h.

3 Mature storm

Warm, moist air continues to rise from the ocean and forms clouds in bands around the eye of the storm. Cool, dry air sinks through the eye and also flows out between the cloud bands at the edges of the storm.

© Corbis; Getty; NASA; SPL

***DID YOU KNOW?** Most of the oxygen we breathe originally came from the activity of photosynthetic organisms in the ocean*

5 Deadliest

An entire ocean poised and ready for destruction

Beneath the Pacific Ocean lies a patchwork of molten terror known as the Ring Of Fire. Earth's crust is made up of tectonic plates that fit together like a jigsaw, floating over a layer of molten rock. At boundary zones, plates rub against each other, push against one another or pull away from one another, each with differing consequences. In the Pacific Ring Of Fire, the landmasses that surround the ocean are at the boundaries of these plates. Home to 90 per cent of earthquakes, the Ring Of Fire is a hotbed of tectonic activity.

Where: South America, North America, across the Bering Strait, Japan and New Zealand
Ocean: Pacific Ocean

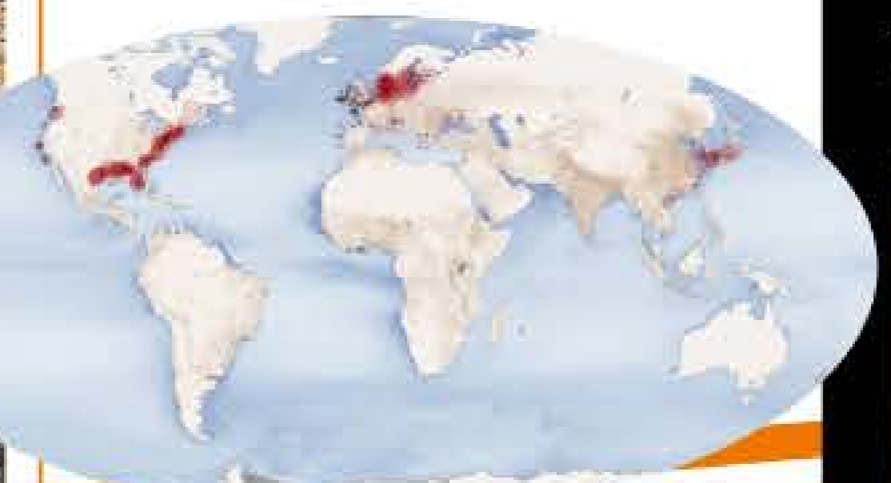
In 2011, an earthquake caused devastation in Japan, which is on the edge of the Ring of Fire

Where: Gulf of Mexico dead zone
Ocean: Atlantic Ocean

6 Most polluted

The dead zone in the Gulf of Mexico is one of the most extreme cases of ocean pollution. It covers almost 17,000 square kilometres of hypoxic water – where very little or no oxygen is present. Nothing can grow there, as almost all organisms require oxygen to survive. Dead zones are caused by nutrient runoff from the land (such as agricultural fertilisers) that cause an excess of algal growth. When the algae dies, it decomposes and consumes all of the oxygen in the water.

Dead zones occur in various oceans and inland water bodies, shown here with red dots

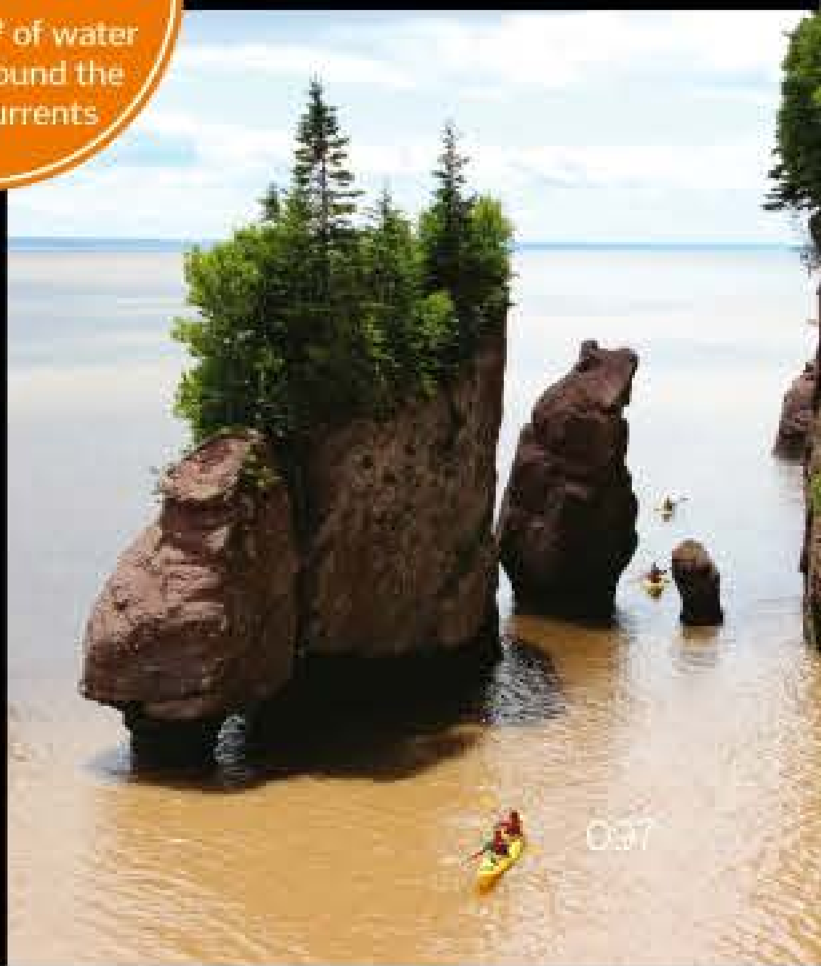


Where: Bay Of Fundy, Canada
Ocean: Atlantic Ocean

7 Most extreme tides

At the head of the Bay of Fundy, at the right time of the month, the difference in high tide and low tide can be a huge 16 metres. When the tide is this high, the bay fills and empties 100 billion tons of seawater during each tidal cycle. The huge tide is a result of the bay's shape and depth, as the water within the bay oscillates (like water sloshing from one end of a bathtub to another) in sync with tides from the Atlantic.

The Bay of Fundy stretches for 270km along Canada's east coast and is a tourist hotspot



Where: Surrounding Antarctica
Ocean: Southern Ocean

8 Coldest

Welcome to life in the liquid freezer

At the very bottom of the globe, surrounding frozen Antarctica, swirls the untameable Southern Ocean. It's home to some of the fastest winds and tallest waves, and also boasts the largest ocean current (the Antarctic Circumpolar Current) that transports more water than all the world's rivers combined. Temperatures can reach a bitterly cold -2 degrees Celsius, because the ocean's salinity lowers its freezing point.

Animals that live in the Southern Ocean also have to adapt to survive. Extra layers of blubber and super-insulating feathers are just a few adaptations, but one of the most extreme has to be that of the Antarctic icefish. This critter has evolved a type of 'antifreeze' protein to prevent ice crystals forming in its body when the temperature plummets.

An incredible feat of survival, the icefish can survive temperatures of -2°C

1,000 YEARS
Time for $1m^3$ of water to travel around the world's currents

10,000–50,000
Number of icebergs produced in the Arctic annually

The Southern Ocean is home to the coldest and stormiest waters on Earth

9 Deepest

Where: Mariana Trench
Ocean: Pacific Ocean

Take a breath and dive deeper than Everest is tall

Surviving in the abyss

What lives in the deepest parts of the ocean?

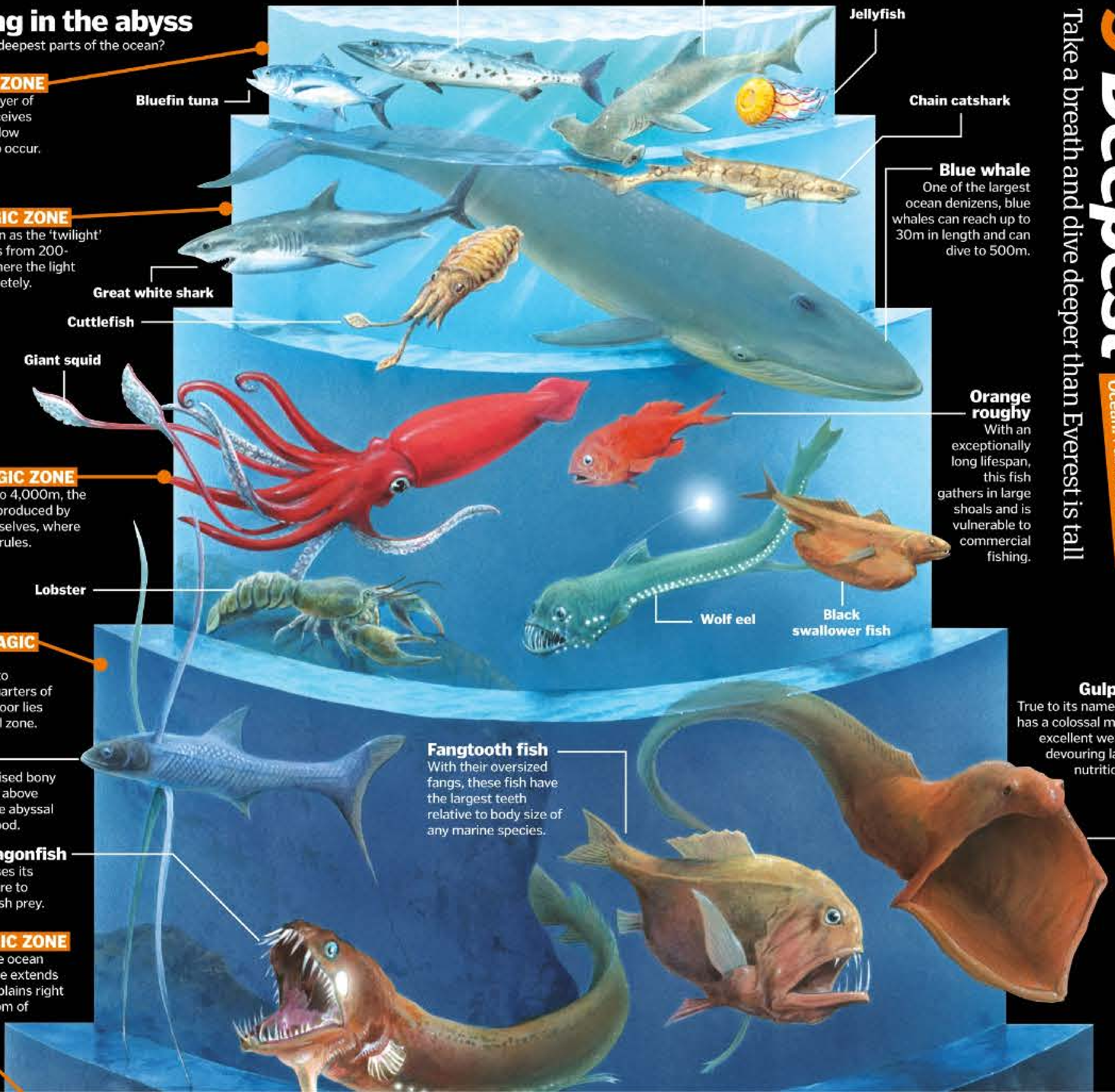
EPIPELAGIC ZONE
The uppermost layer of oceanic water receives enough light to allow photosynthesis to occur.

MESOPELAGIC ZONE
Sometimes known as the 'twilight' zone, this extends from 200-1,000m down, where the light disappears completely.

BATHYPELAGIC ZONE
Extending down to 4,000m, the only light here is produced by the animals themselves, where bioluminescence rules.

ABYSSOPELAGIC ZONE
Stretching down to 6,000m, three quarters of the deep-ocean floor lies within the abyssal zone.

HADOPELAGIC ZONE
Encompassing the ocean trenches, this zone extends from the abyssal plains right down to the bottom of the world.



Blue whale
One of the largest ocean denizens, blue whales can reach up to 30m in length and can dive to 500m.

Orange roughy
With an exceptionally long lifespan, this fish gathers in large shoals and is vulnerable to commercial fishing.

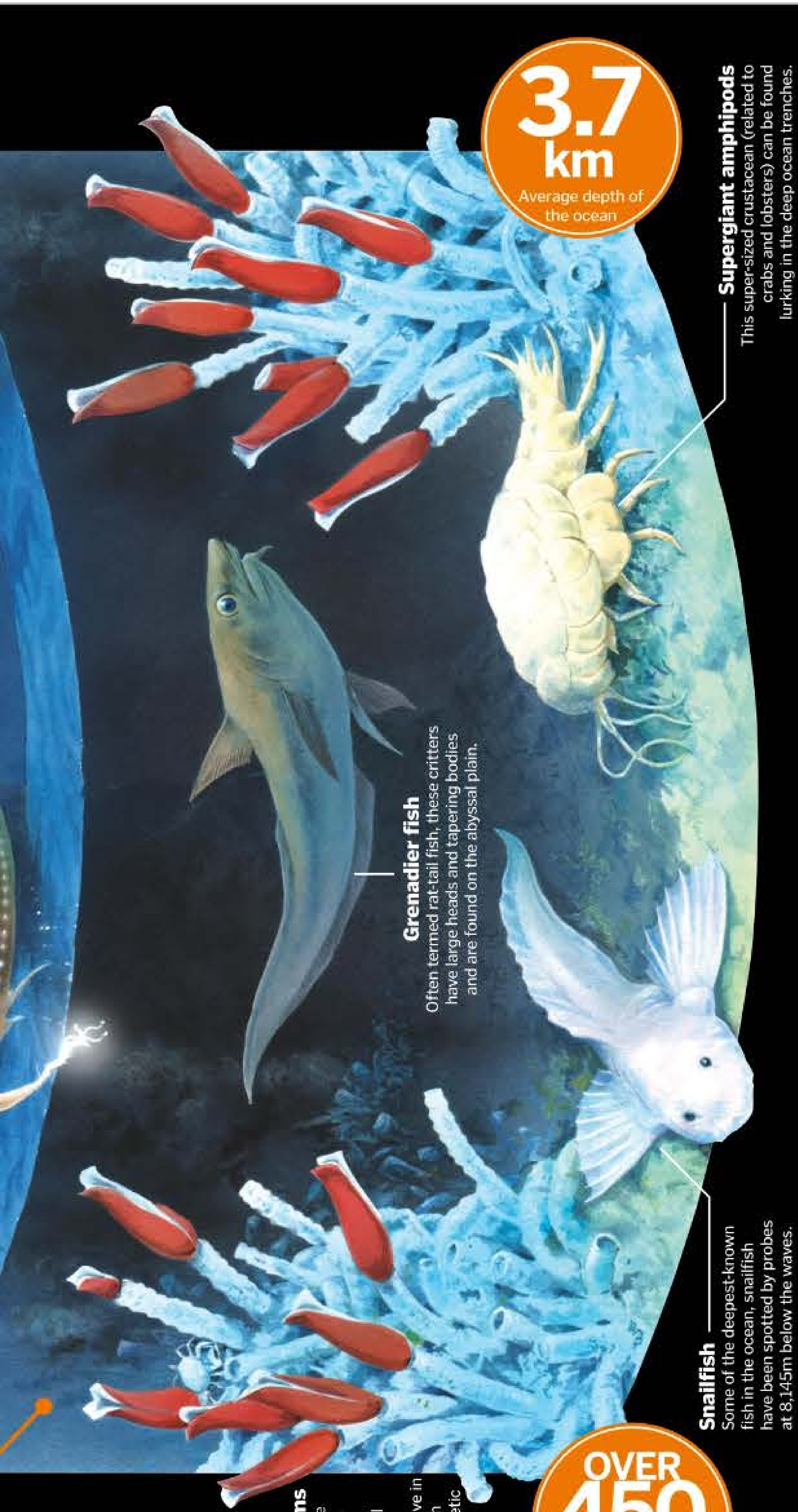
Gulper eel
True to its name, this eel has a colossal mouth, an excellent weapon for devouring large and nutritious prey.

Fangtooth fish
With their oversized fangs, these fish have the largest teeth relative to body size of any marine species.

Tripod fish
This fish's specialised bony fins help it to rest above the thick silt of the abyssal plain in wait for food.

Deep-sea dragonfish
The dragonfish uses its bioluminescent lure to attract and ambush prey.

DID YOU KNOW? *In a cubic kilometre of seawater, there are approximately 26 million tons of salt (as sodium chloride)*



3.7 km
Average depth of the ocean

Supergiant amphipods
This super-sized crustacean (related to crabs and lobsters) can be found lurking in the deep ocean trenches.

Grenadier fish
Often termed rat-tail fish, these critters have large heads and tapering bodies and are found on the abyssal plain.

Snailfish
Some of the deepest-known fish in the ocean, snailfish have been spotted by probes at 8,145m below the waves.

Tubeworms
Living in large communities around hydrothermal vents, huge tubeworms live in harmony with chemosynthetic bacteria.

OVER 450
Number of volcanoes in the Pacific Ring of Fire

At the very bottom of the ocean, just shy of 11,000 metres below the surface, sunlight is long gone and all that is left is inky blackness. The Challenger Deep is part of the Mariana Trench, a deep score across the sea floor of the Pacific basin that is formed at a subduction zone, where one tectonic plate disappears beneath another. It is the deepest point in Earth's oceans, and with over ten kilometres of water overhead, the hydrostatic pressure is 1,100 atmospheres – the equivalent of inverting the Eiffel tower and balancing it on your big toe.

The water temperature at the bottom of the Challenger Deep is just above freezing, and the trench is filled with clouds of silt, formed from millions of years of ocean garbage falling from above and slowly rotting away. However, despite the pressure, darkness and coldness of the environment, life still prevails! The deep sea is home to an array of strange and wonderful creatures that survive against all odds, having developed clever mechanisms to deal with the extreme conditions.

The Challenger Deep was first explored in 1960 by Swiss scientist Jacques Piccard and US Navy Lieutenant Don Walsh in the Trieste submersible, which set a record by diving to a depth of just over 10,915 metres. Since that seminal dive there have been multiple attempts by both manned and unmanned vehicles, the most recent made by explorer and film-maker James Cameron, who managed to reach a depth of 10,898 metres in his Deepsea Challenger submarine.

Hydrothermal vents

Often forming at mid-ocean ridges where tectonic activity is high, hydrothermal vents are cracks and fissures in the Earth's crust where super-heated water escapes into the ocean. The temperature of this water can reach 400 degrees Celsius, but doesn't boil due to the extreme pressure.

Hydrothermal vents can support vast communities of life. The organisms that live around them use chemosynthesis – as opposed to photosynthesis – to survive. The primary producers of a chemosynthetic food chain are microbes that use the chemicals expelled by the vents as the basis to create energy, akin to how plants on land use sunlight.

Seawater filters through the rocks into the crust, becomes super-heated and is expelled through vents

© Corbis

ROCKS, GEMS & FOSSILS

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How cenotes form

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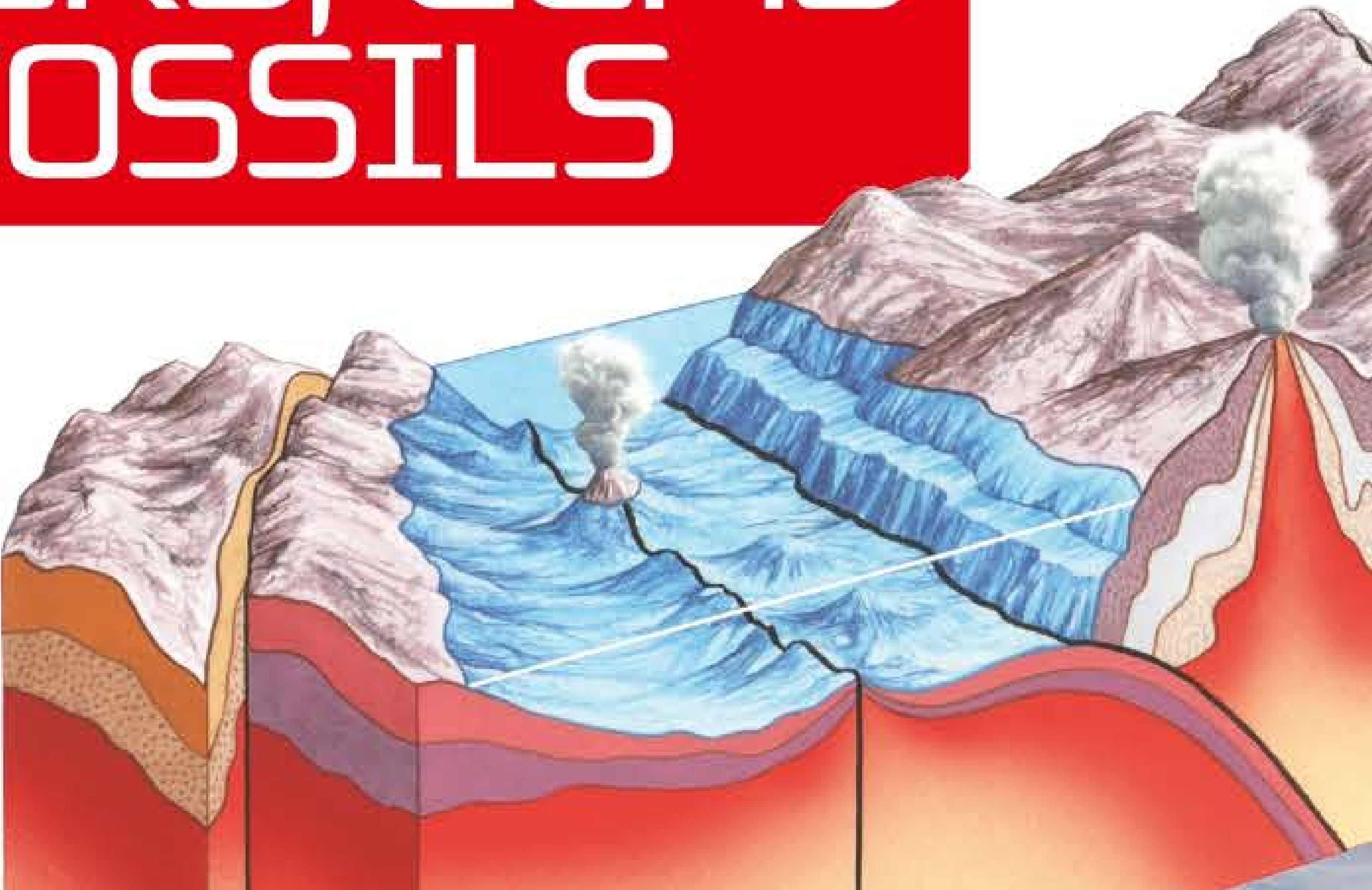
Measuring earthquakes



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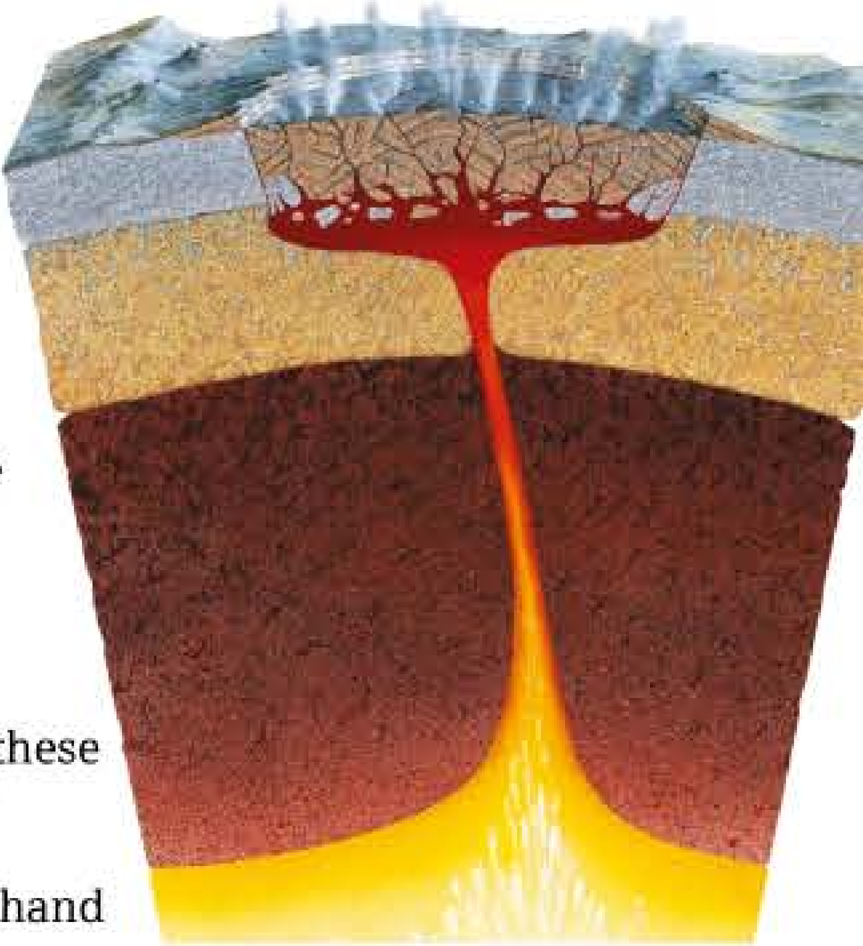

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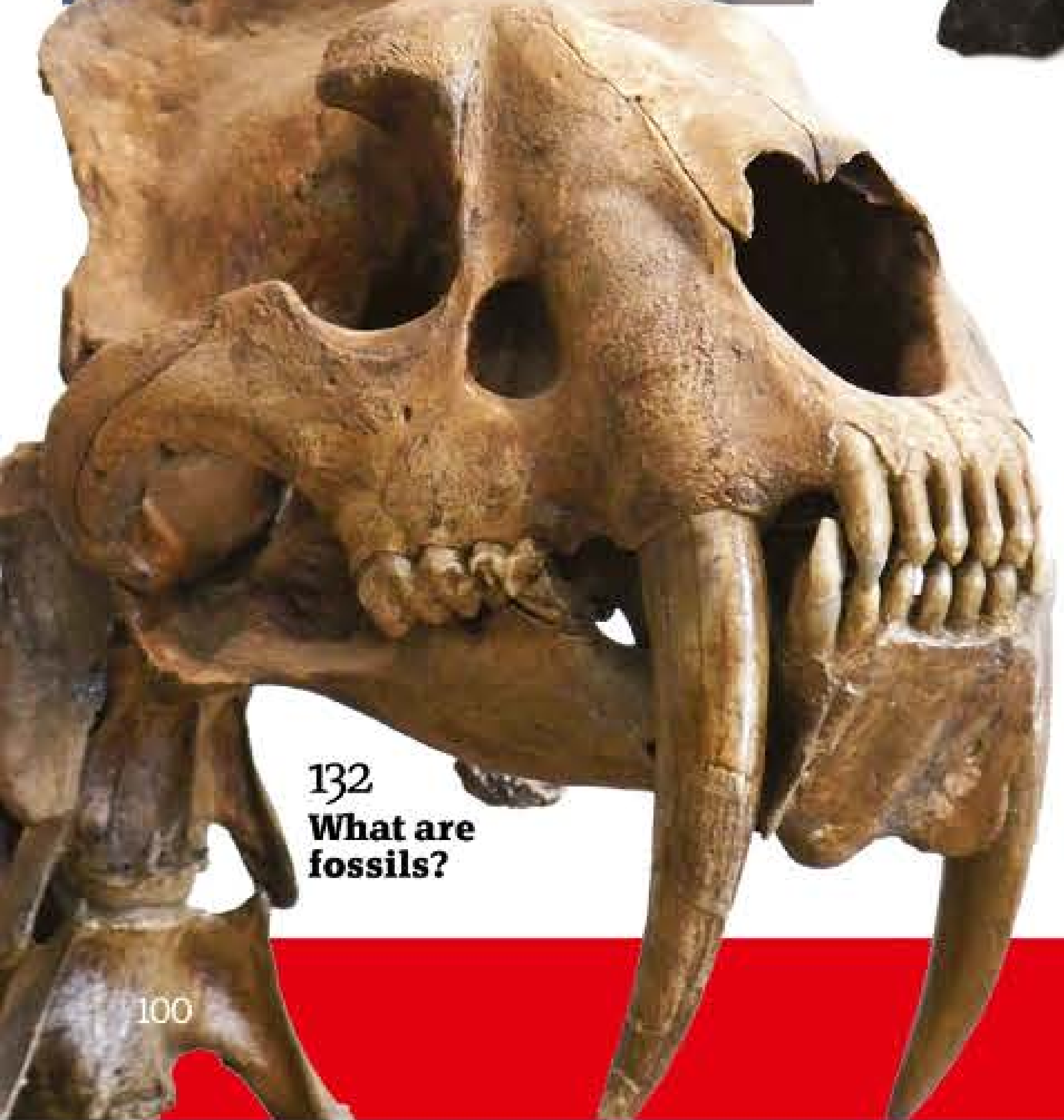

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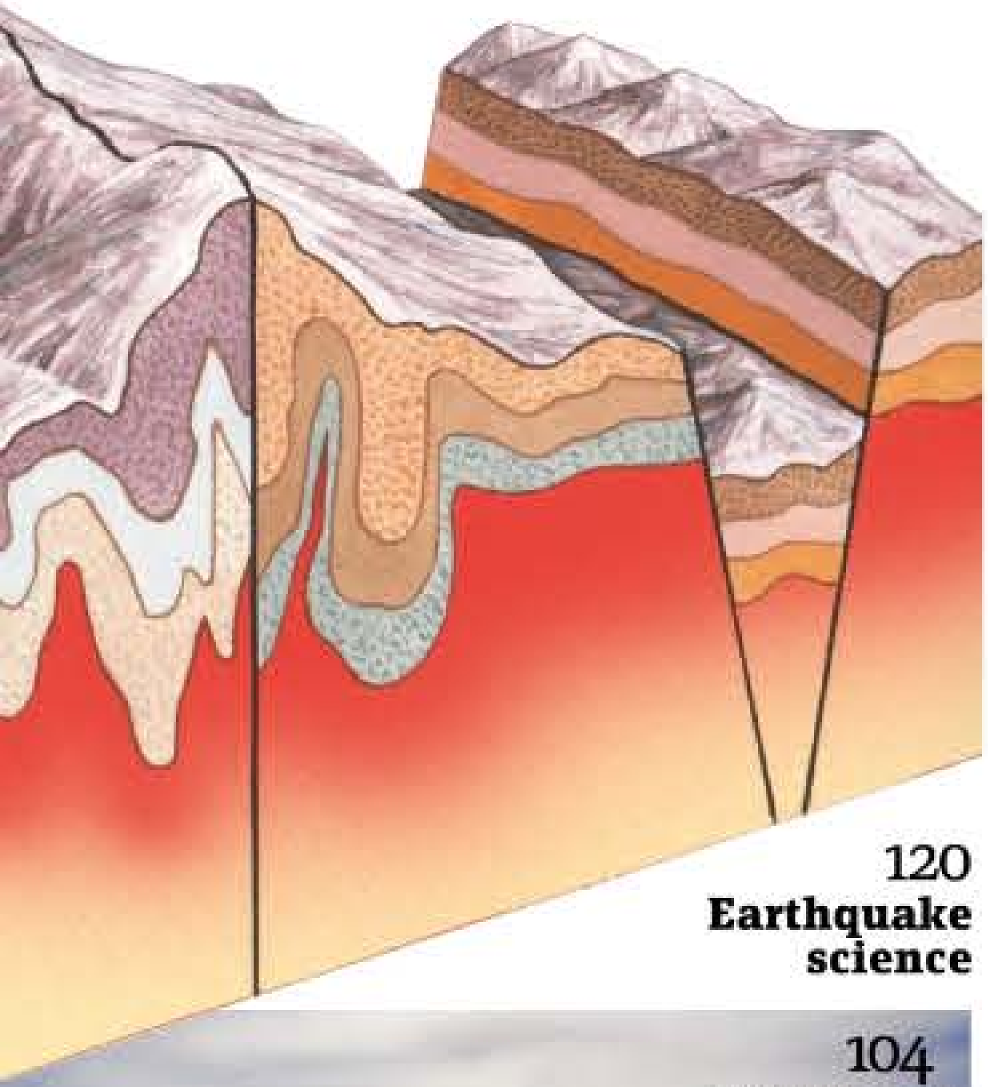

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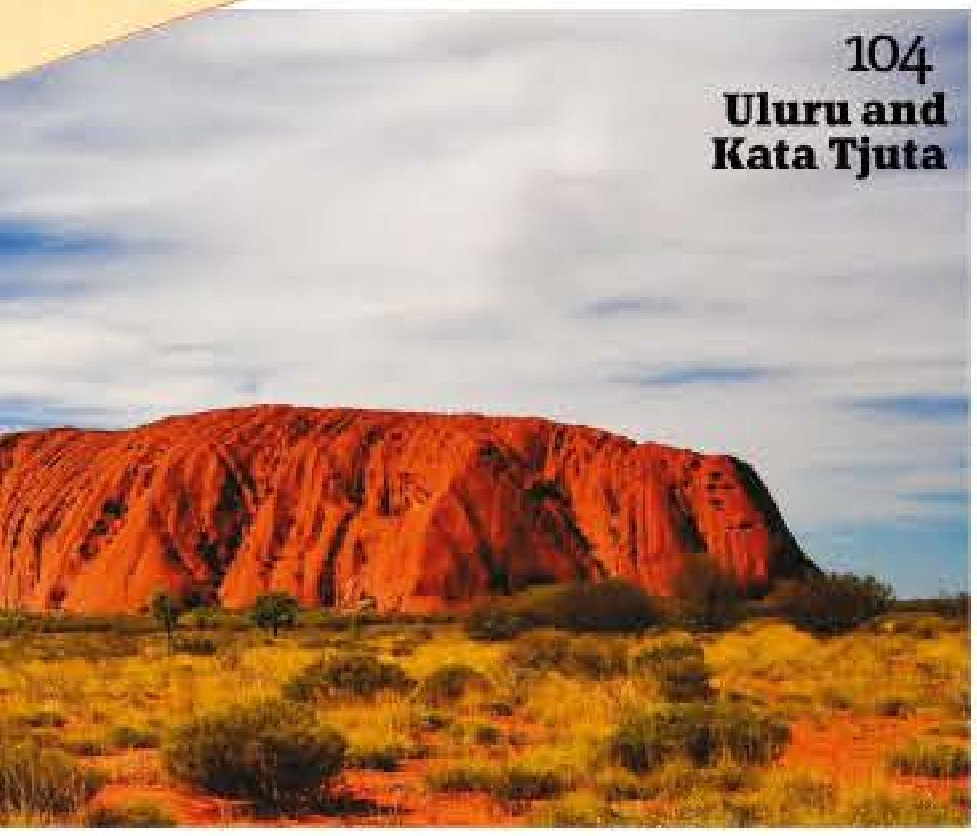

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The development of the curious subterranean spikes

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A unique insight into what once lived on Earth

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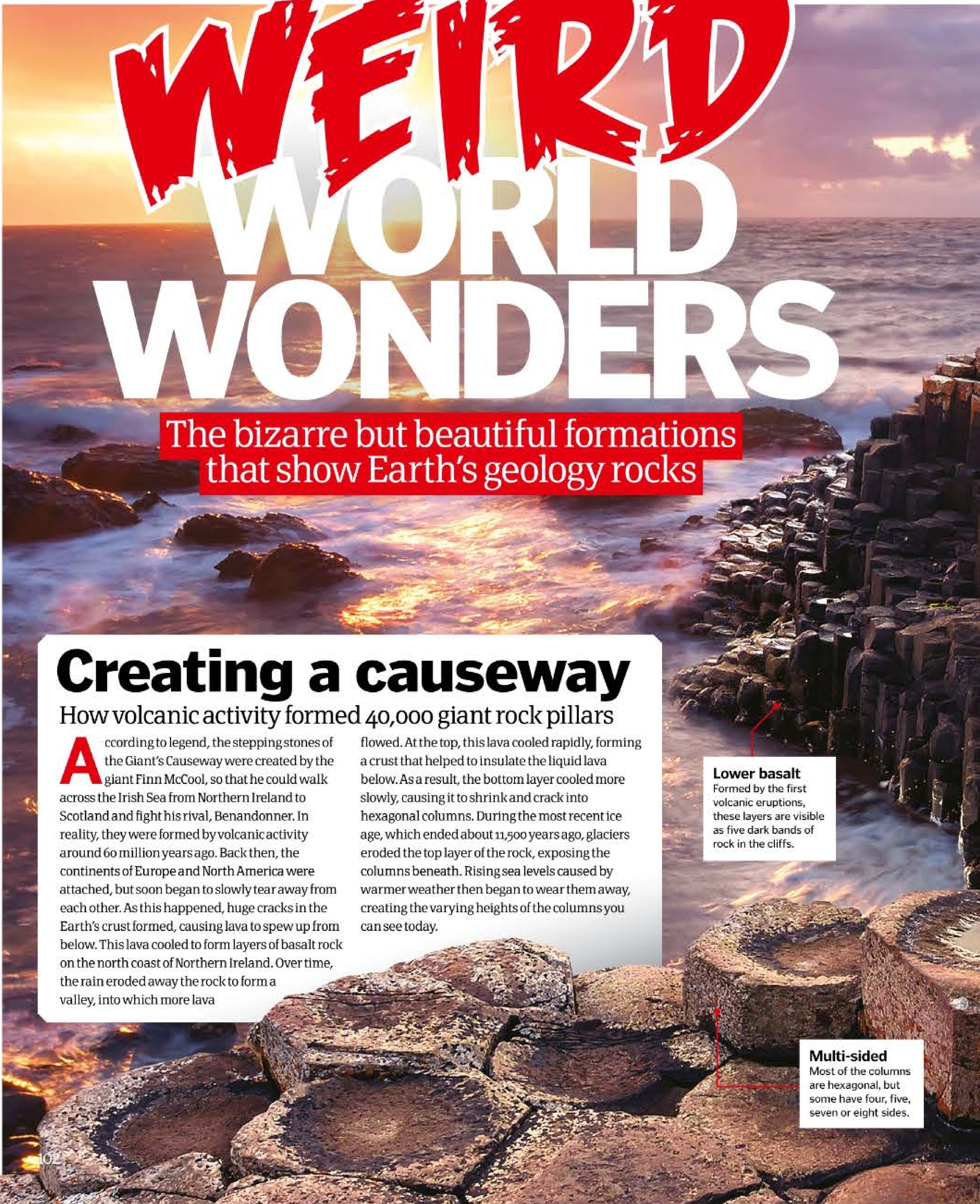
WEIRD WORLD WONDERS

The bizarre but beautiful formations that show Earth's geology rocks



Lower basalt
Formed by the first volcanic eruptions, these layers are visible as five dark bands of rock in the cliffs.

Multi-sided
Most of the columns are hexagonal, but some have four, five, seven or eight sides.

Creating a causeway

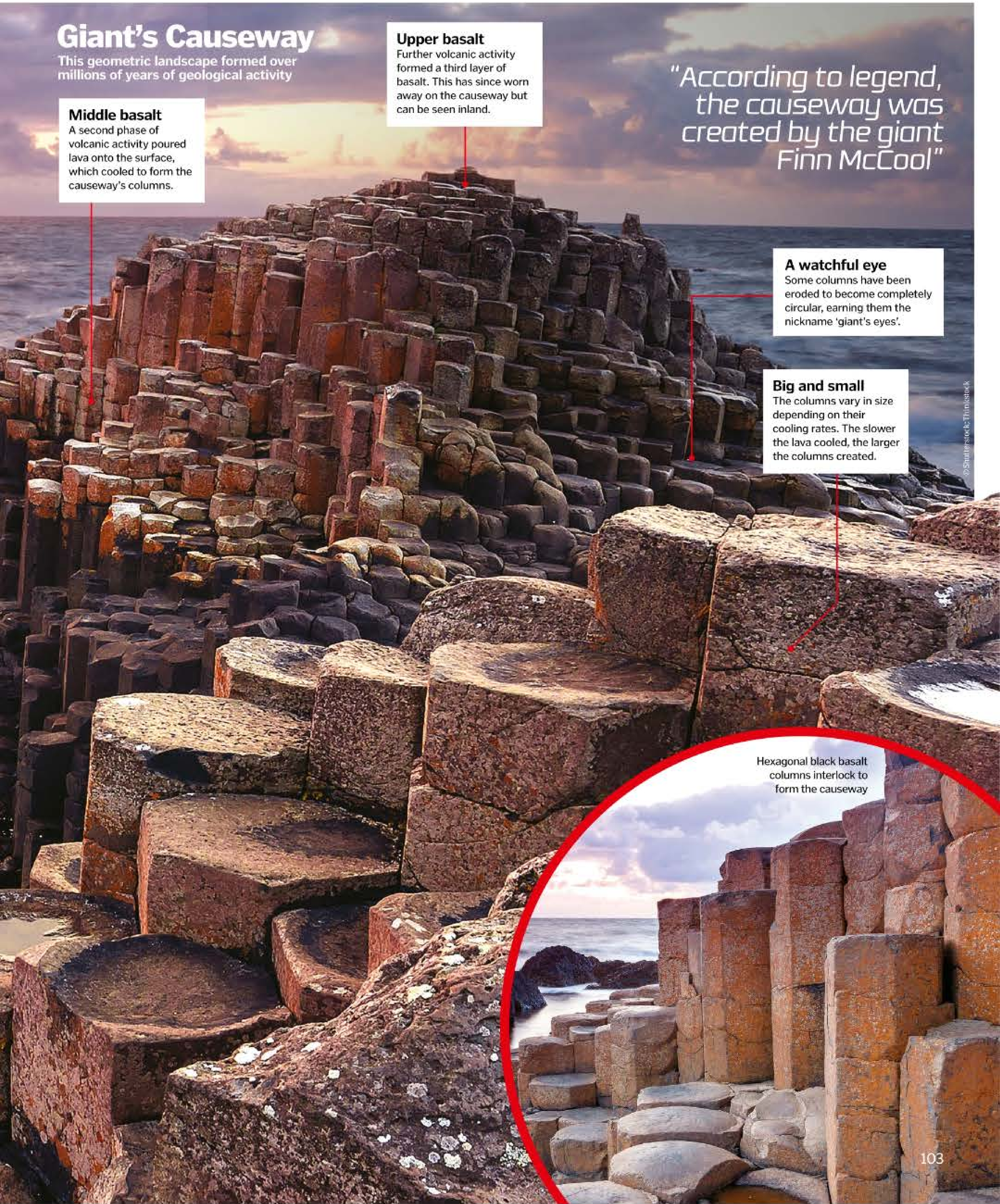
How volcanic activity formed 40,000 giant rock pillars

According to legend, the stepping stones of the Giant's Causeway were created by the giant Finn McCool, so that he could walk across the Irish Sea from Northern Ireland to Scotland and fight his rival, Benandonner. In reality, they were formed by volcanic activity around 60 million years ago. Back then, the continents of Europe and North America were attached, but soon began to slowly tear away from each other. As this happened, huge cracks in the Earth's crust formed, causing lava to spew up from below. This lava cooled to form layers of basalt rock on the north coast of Northern Ireland. Over time, the rain eroded away the rock to form a valley, into which more lava flowed. At the top, this lava cooled rapidly, forming a crust that helped to insulate the liquid lava below. As a result, the bottom layer cooled more slowly, causing it to shrink and crack into hexagonal columns. During the most recent ice age, which ended about 11,500 years ago, glaciers eroded the top layer of the rock, exposing the columns beneath. Rising sea levels caused by warmer weather then began to wear them away, creating the varying heights of the columns you can see today.

DID YOU KNOW? *The Giant's Causeway was the first UK natural World Heritage Site to be documented using 3D laser scanners*

Giant's Causeway

This geometric landscape formed over millions of years of geological activity



Middle basalt
A second phase of volcanic activity poured lava onto the surface, which cooled to form the causeway's columns.

Upper basalt
Further volcanic activity formed a third layer of basalt. This has since worn away on the causeway but can be seen inland.

> "According to legend, the causeway was created by the giant Finn McCool"

A watchful eye
Some columns have been eroded to become completely circular, earning them the nickname 'giant's eyes'.

Big and small
The columns vary in size depending on their cooling rates. The slower the lava cooled, the larger the columns created.

Hexagonal black basalt columns interlock to form the causeway

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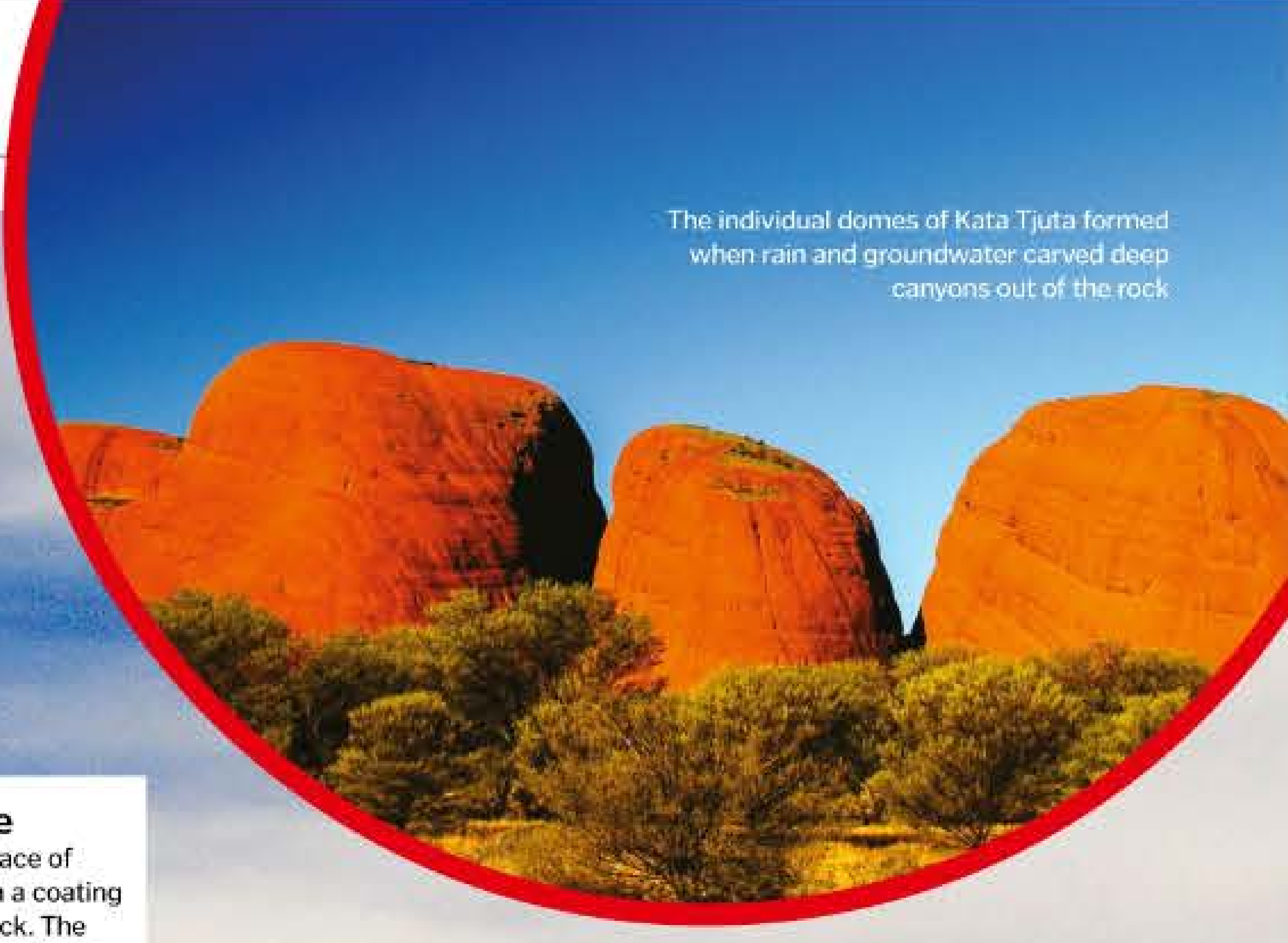
OZ ODDITIES

The Australian outback is home to many strange landmarks

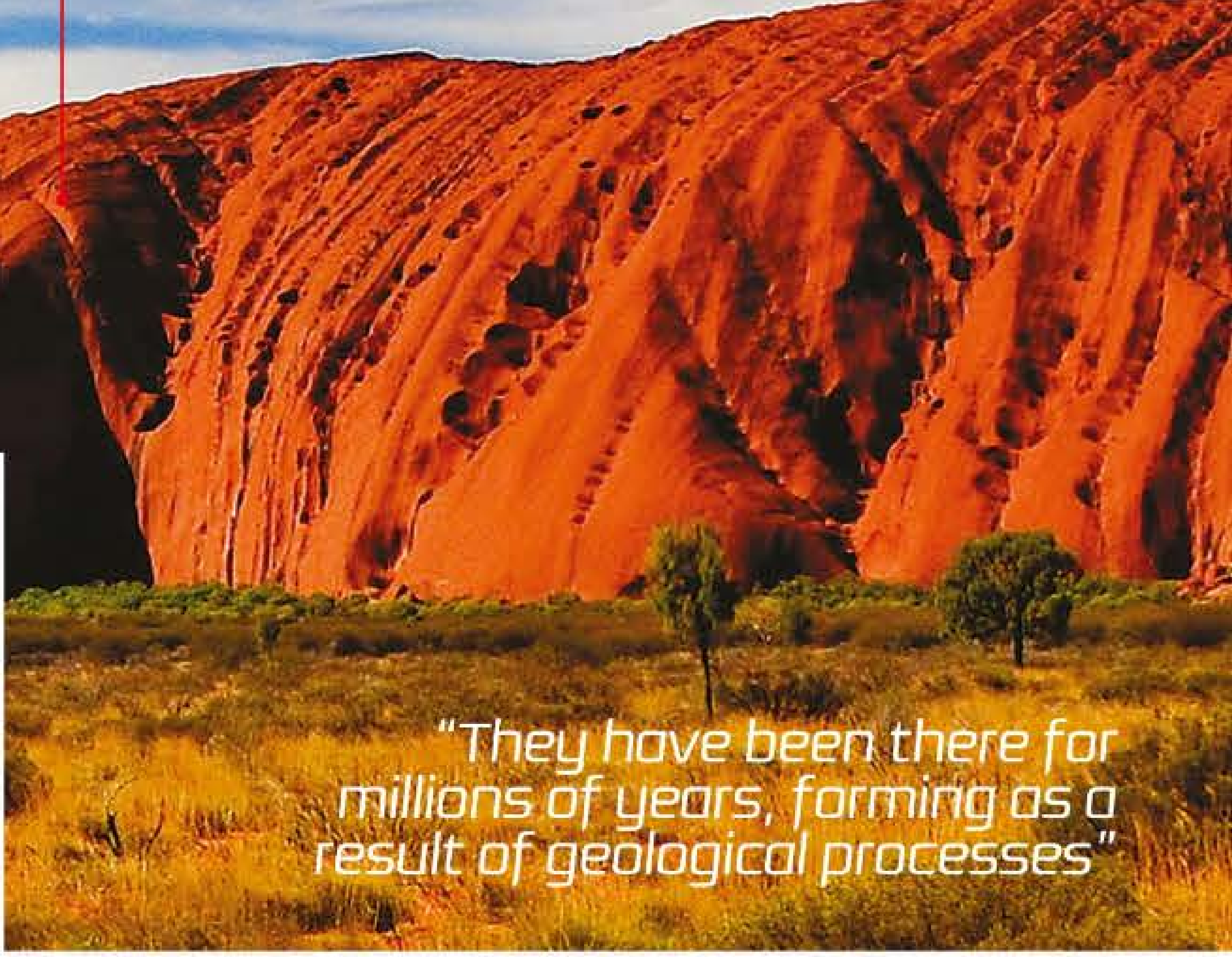


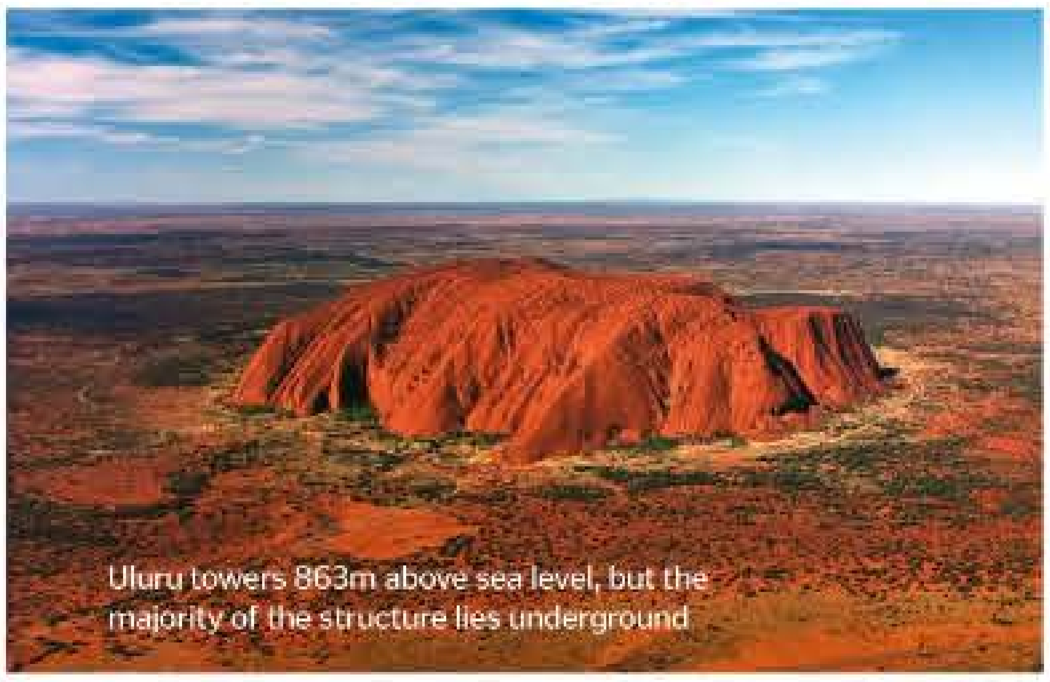
The individual domes of Kata Tjuta formed when rain and groundwater carved deep canyons out of the rock

Uluru and Kata Tjuta

Standing proud against the flat horizon of the Australian outback are two enormous sandstone and rock formations named Uluru and Kata Tjuta. They may look a little out of place but they have been there for millions of years, forming as a result of geological processes.

Flaky surface
Close up, the surface of Uluru is grey, with a coating of red flakes of rock. The flakes' colour is due to the iron in the rock rusting.



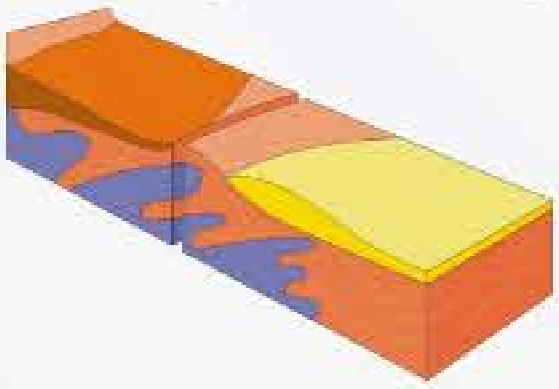


Uluru towers 863m above sea level, but the majority of the structure lies underground

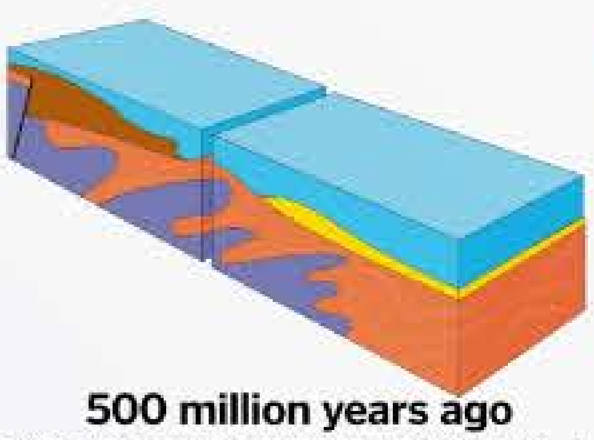
> "They have been there for millions of years, forming as a result of geological processes"

Rocky history

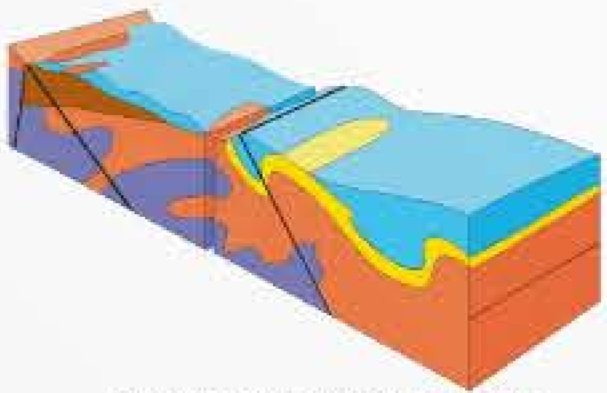
How did the magnificent Uluru and Kata Tjuta rocks form?



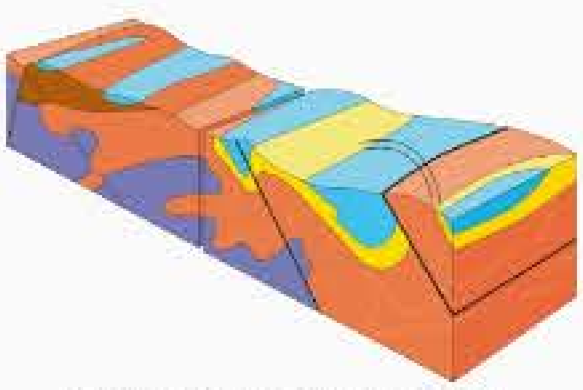
550 million years ago
Rainwater eroded the mountains in the Petermann Ranges, depositing sediment in two fan shapes, one of sand and one of rock, onto the surrounding plain.



500 million years ago
The area was covered in a shallow sea. A seabed of sand and mud compressed the fans, turning the rock into conglomerate rock, and the sand into arkose sandstone.

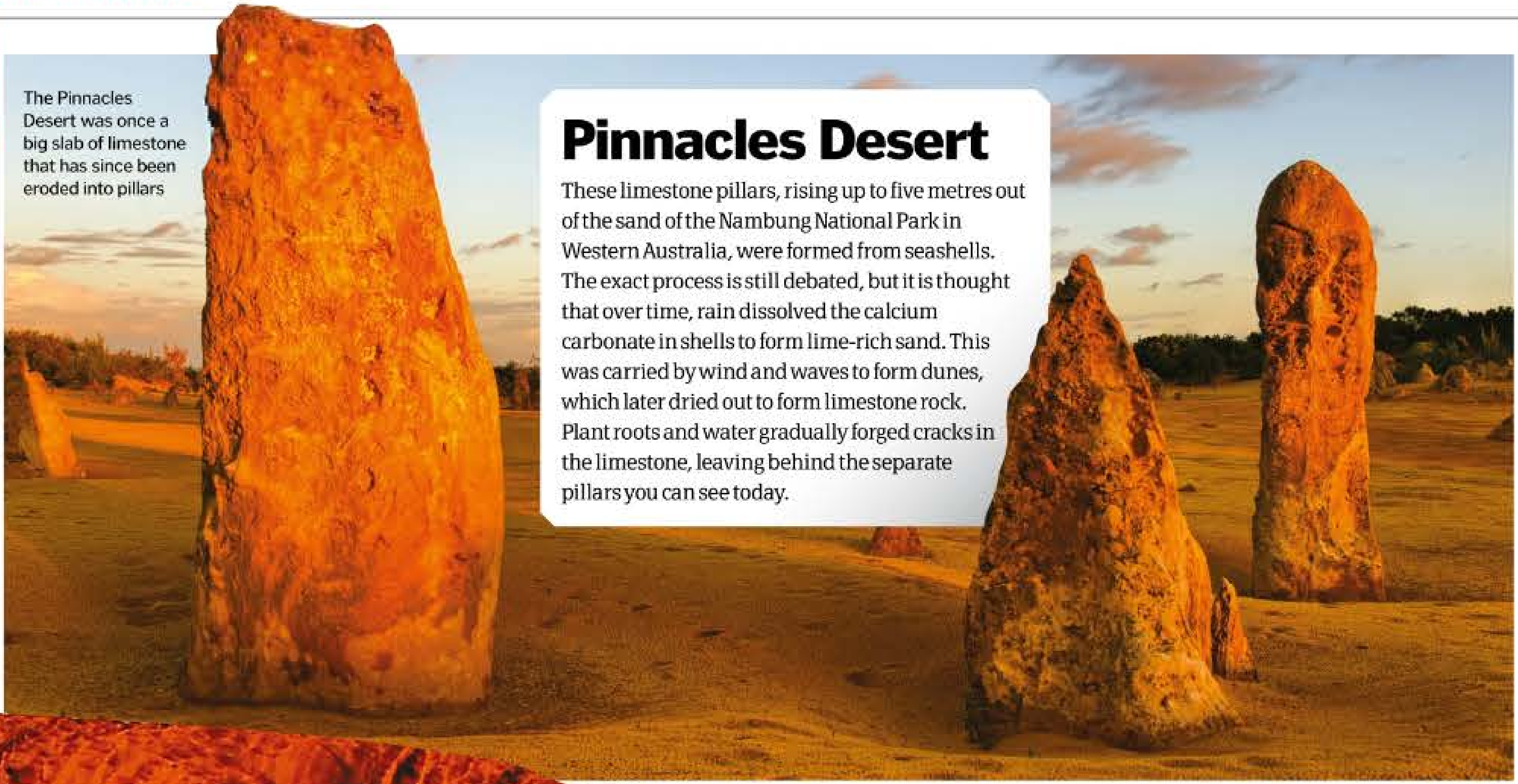


400 million years ago
The sea receded again, and the rocks started to fold and tilt under the immense force of the Earth's shifting tectonic plates.



400 million years ago (continued)
The rocky fan tilted by about 20 degrees, becoming Kata Tjuta. The sandstone fan tilted almost 90 degrees, becoming Uluru.

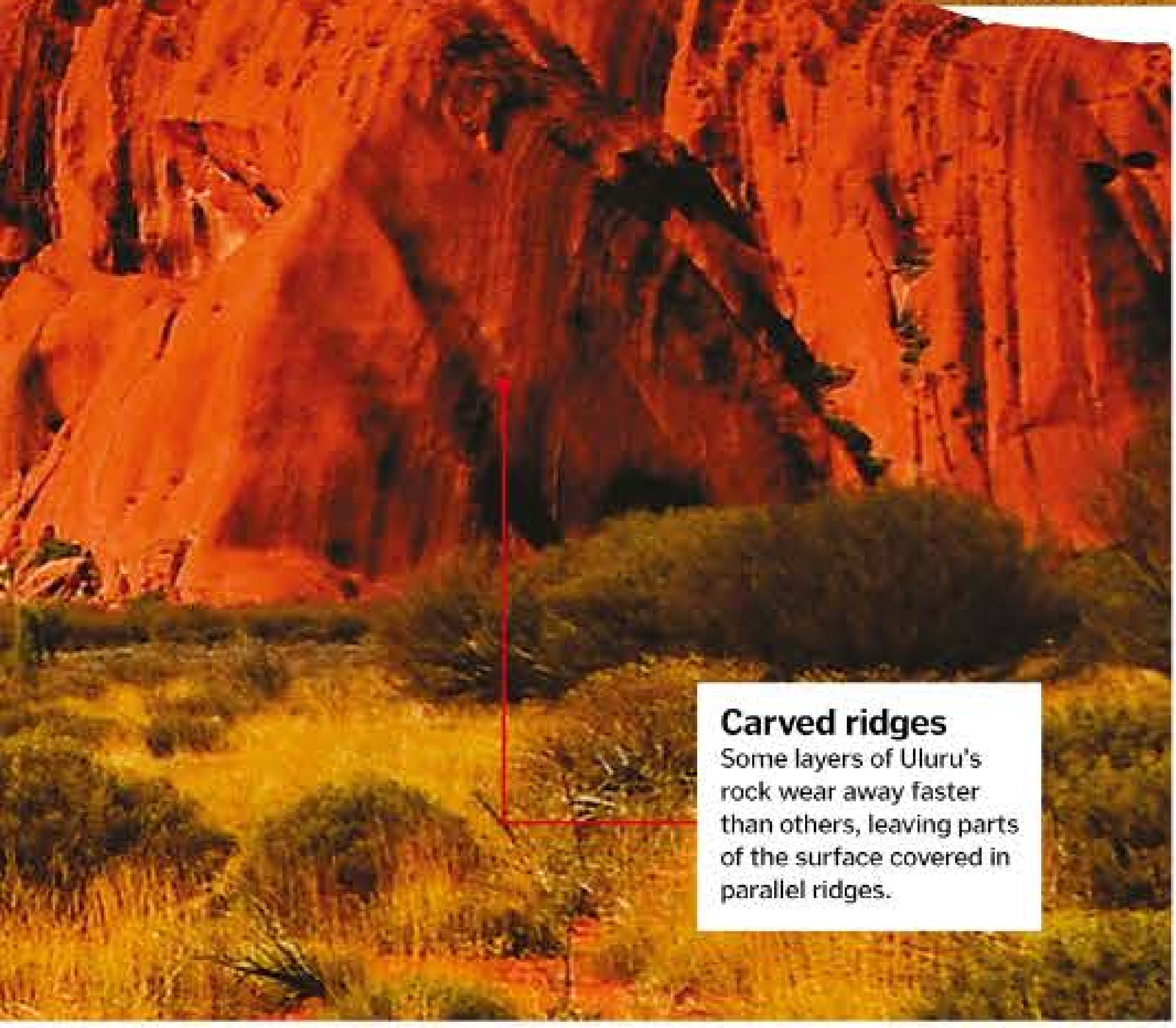
DID YOU KNOW? *Uluru and Kata Tjuta are owned by the native Aboriginal people, but they lease the area to Parks Australia*



The Pinnacles Desert was once a big slab of limestone that has since been eroded into pillars

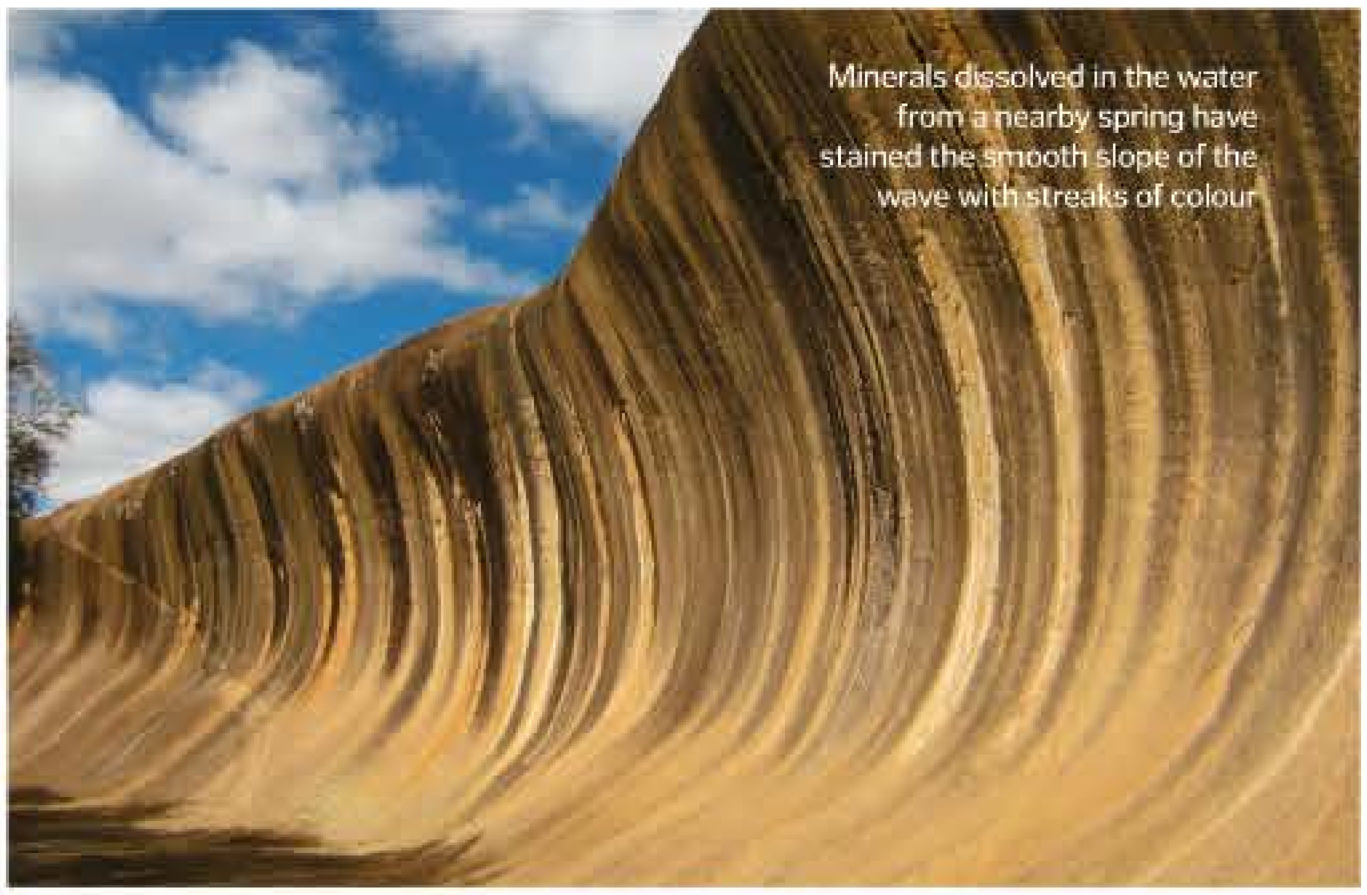
Pinnacles Desert

These limestone pillars, rising up to five metres out of the sand of the Nambung National Park in Western Australia, were formed from seashells. The exact process is still debated, but it is thought that over time, rain dissolved the calcium carbonate in shells to form lime-rich sand. This was carried by wind and waves to form dunes, which later dried out to form limestone rock. Plant roots and water gradually forged cracks in the limestone, leaving behind the separate pillars you can see today.



Carved ridges

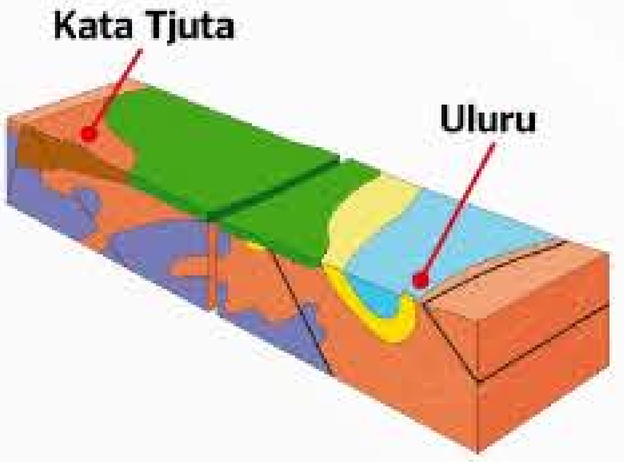
Some layers of Uluru's rock wear away faster than others, leaving parts of the surface covered in parallel ridges.



Minerals dissolved in the water from a nearby spring have stained the smooth slope of the wave with streaks of colour

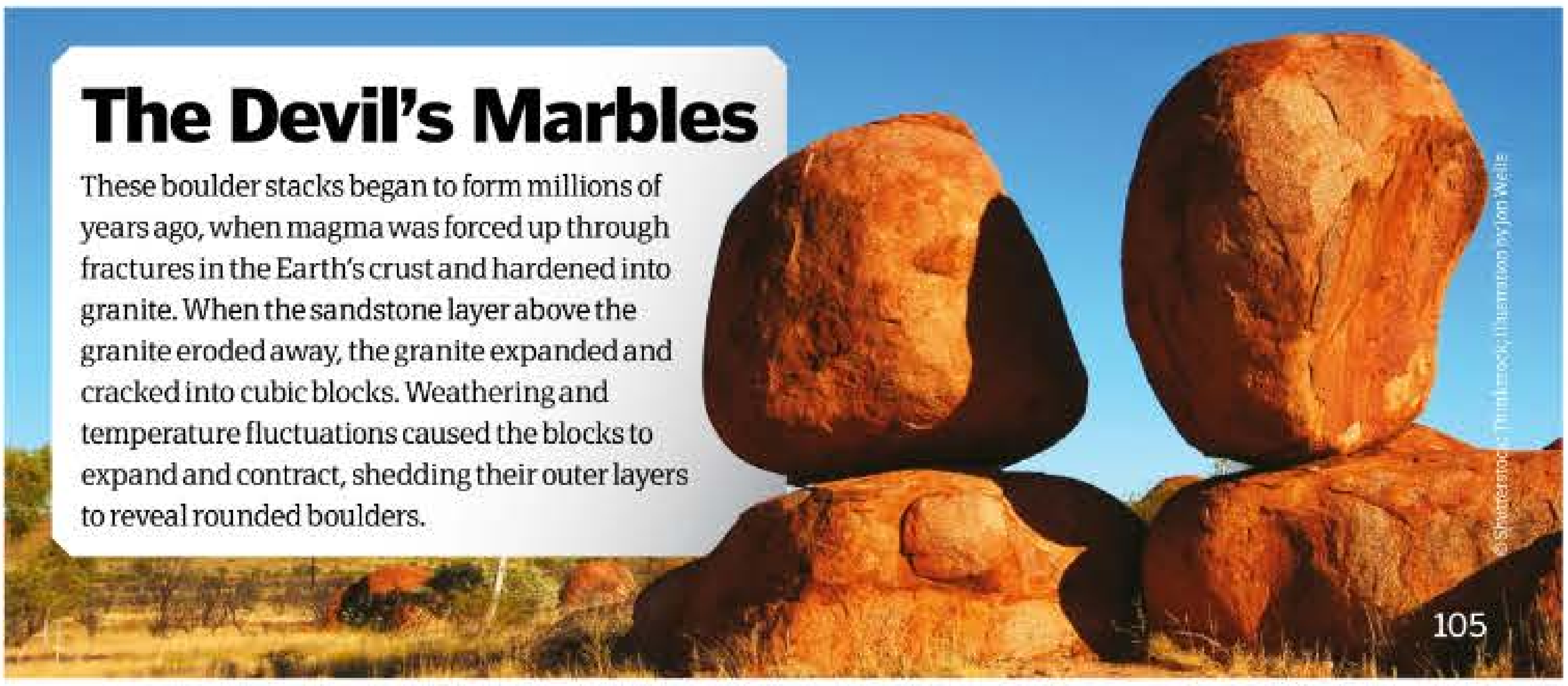
Wave Rock

This granite rock was buried by soil, exposing the top. As granite does not erode easily, the top remained intact, but as rain moistened the soil below, it became acidic and dissolved the base of the rock. The soil has since eroded away, exposing the 15-metre-tall overhanging wave.



500,000 years ago

As the climate became drier, wind-blown sand partly filled the valley between the two slabs of rock that were now protruding from the surface.



The Devil's Marbles

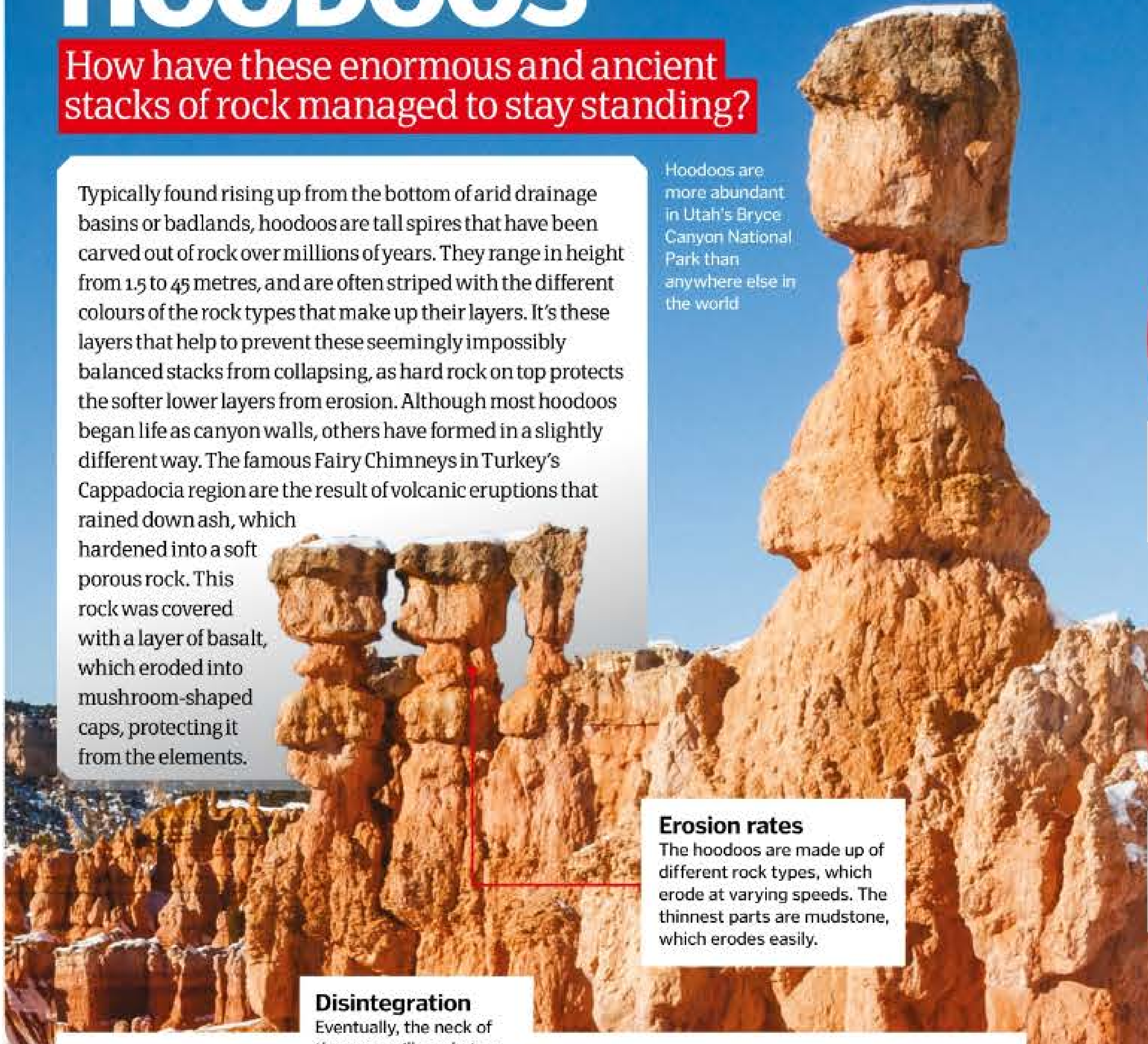
These boulder stacks began to form millions of years ago, when magma was forced up through fractures in the Earth's crust and hardened into granite. When the sandstone layer above the granite eroded away, the granite expanded and cracked into cubic blocks. Weathering and temperature fluctuations caused the blocks to expand and contract, shedding their outer layers to reveal rounded boulders.

© Shutterstock; Thinkstock; Illustration by Jon Wells

HOODOOS

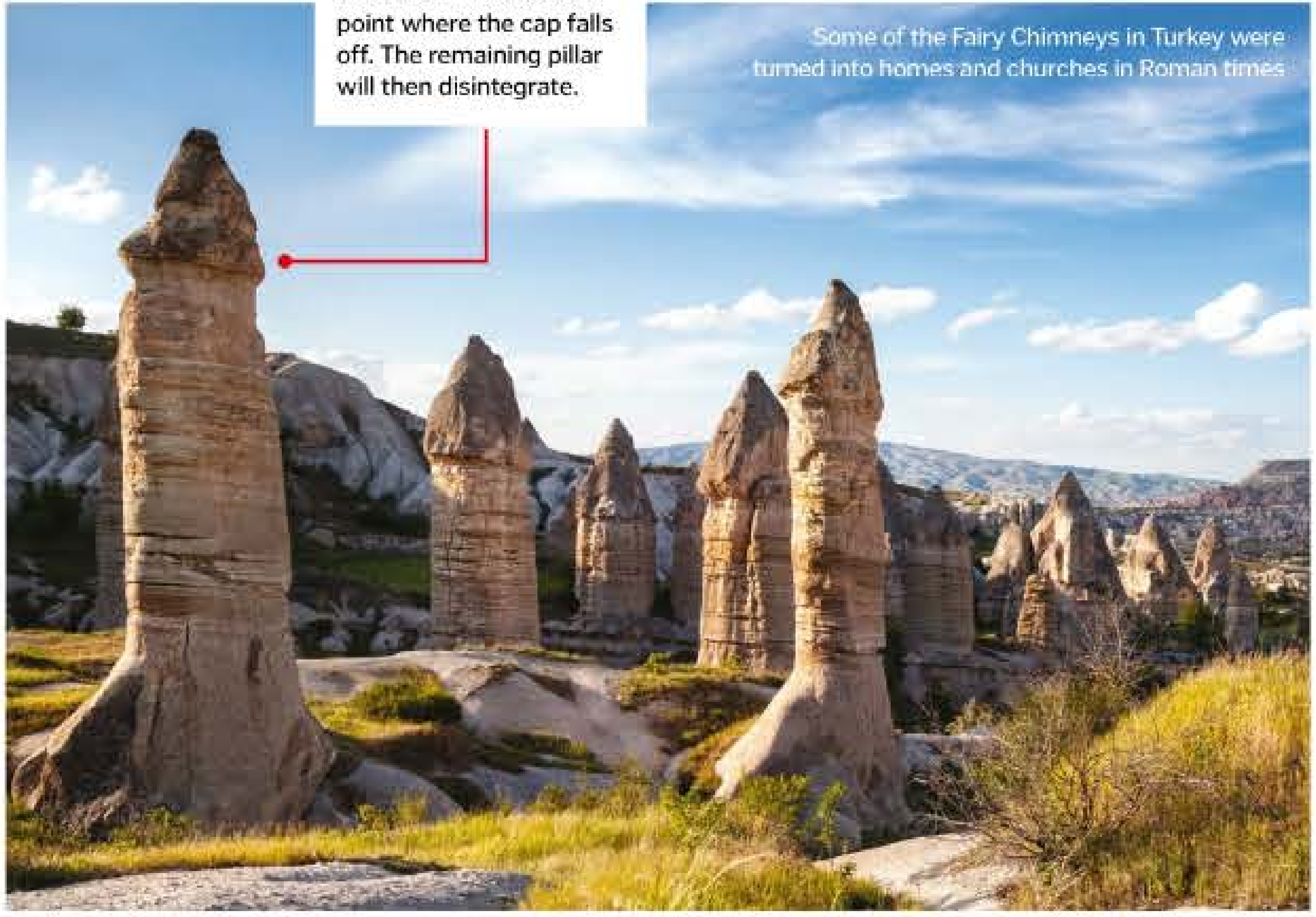
How have these enormous and ancient stacks of rock managed to stay standing?

Typically found rising up from the bottom of arid drainage basins or badlands, hoodoos are tall spires that have been carved out of rock over millions of years. They range in height from 1.5 to 45 metres, and are often striped with the different colours of the rock types that make up their layers. It's these layers that help to prevent these seemingly impossibly balanced stacks from collapsing, as hard rock on top protects the softer lower layers from erosion. Although most hoodoos began life as canyon walls, others have formed in a slightly different way. The famous Fairy Chimneys in Turkey's Cappadocia region are the result of volcanic eruptions that rained down ash, which hardened into a soft porous rock. This rock was covered with a layer of basalt, which eroded into mushroom-shaped caps, protecting it from the elements.



Hoodoos are more abundant in Utah's Bryce Canyon National Park than anywhere else in the world

Erosion rates
The hoodoos are made up of different rock types, which erode at varying speeds. The thinnest parts are mudstone, which erodes easily.

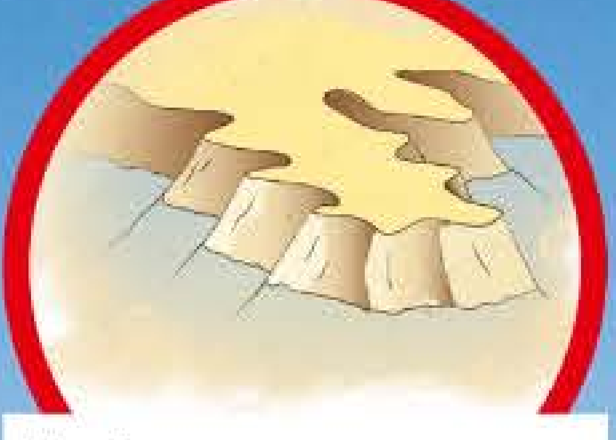


Disintegration
Eventually, the neck of the cone will erode to a point where the cap falls off. The remaining pillar will then disintegrate.

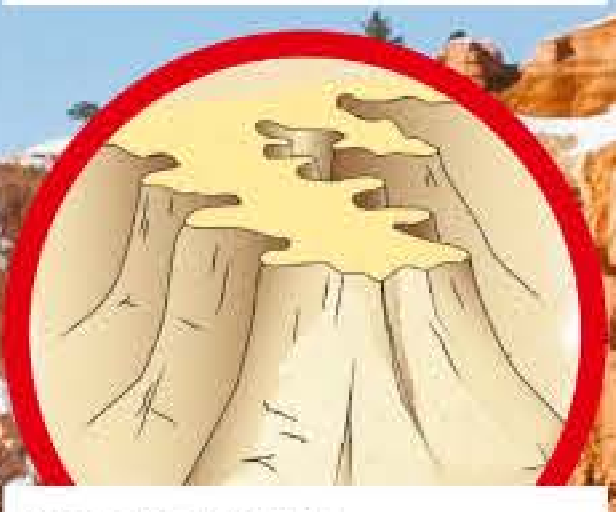
Some of the Fairy Chimneys in Turkey were turned into homes and churches in Roman times

How do hoodoos form?

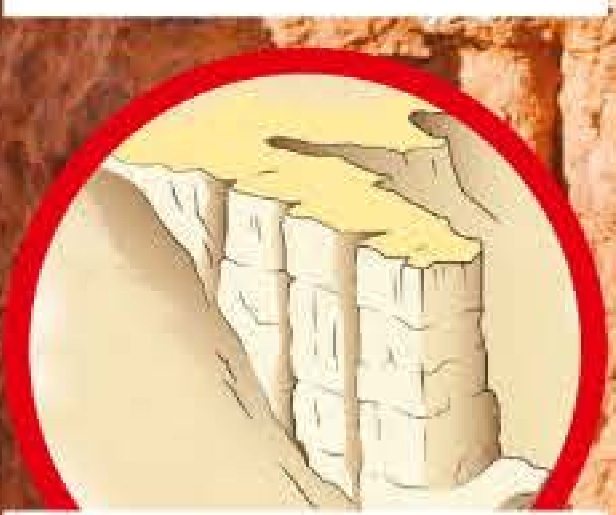
From flooded canyon to rocky pillars, discover how erosion shaped these rock towers



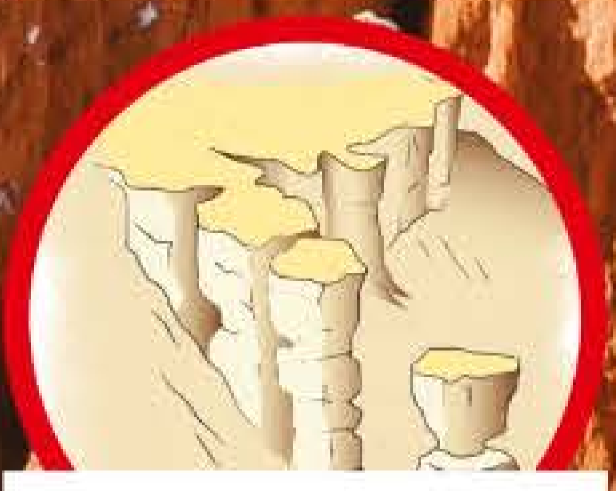
Empty canyon
A vast lake drains away, leaving behind a canyon with a layer of sediment at the bottom.



Receding walls
Water seeps out of the lower rocks, taking rock material with it and eroding away the walls.



Vertical cracks
Acidic rainwater widens cracks, and expands and contracts as it freezes and thaws, eroding the rock further.



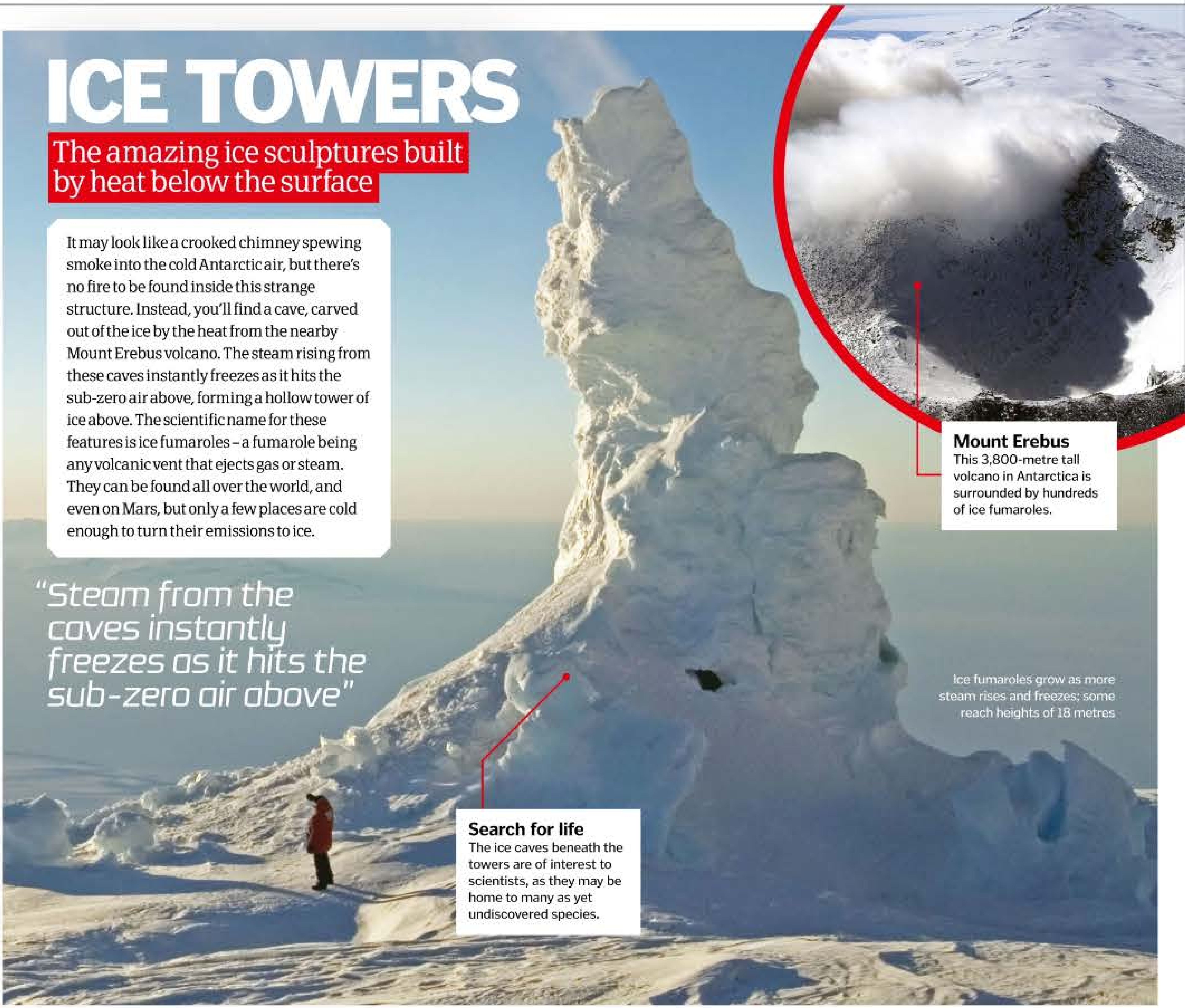
Protective cap
The harder layer of rock on top protects the softer layer beneath it from erosion, forming tall hoodoos.

ICE TOWERS

The amazing ice sculptures built by heat below the surface

It may look like a crooked chimney spewing smoke into the cold Antarctic air, but there's no fire to be found inside this strange structure. Instead, you'll find a cave, carved out of the ice by the heat from the nearby Mount Erebus volcano. The steam rising from these caves instantly freezes as it hits the sub-zero air above, forming a hollow tower of ice above. The scientific name for these features is ice fumaroles – a fumarole being any volcanic vent that ejects gas or steam. They can be found all over the world, and even on Mars, but only a few places are cold enough to turn their emissions to ice.

> "Steam from the caves instantly freezes as it hits the sub-zero air above"



Mount Erebus
This 3,800-metre tall volcano in Antarctica is surrounded by hundreds of ice fumaroles.

Ice fumaroles grow as more steam rises and freezes; some reach heights of 18 metres

Search for life
The ice caves beneath the towers are of interest to scientists, as they may be home to many as yet undiscovered species.

A land of ice and fire

Despite being located in the centre of a stationary tectonic plate, Antarctica still manages to be a hotbed of volcanic activity. This is all down to the West Antarctic Rift, an area where the tectonic plates are slowly moving apart. Along this rift, the Earth's crust has thinned, allowing magma to rise to the surface and create enormous volcanoes. While many of the volcanoes are now extinct, others are still ejecting hot gas and lava, with the most active being Mount Erebus on Ross Island. Mount Erebus is one of only a few volcanoes to have an open lava lake. While the central crater on most volcanoes is covered with a solid slab of cooled molten rock, the one on this volcano is uncovered, exposing the hot magma inside. Several low-level eruptions occur every day, ejecting scorching lava bombs onto the surrounding landscape as a result.

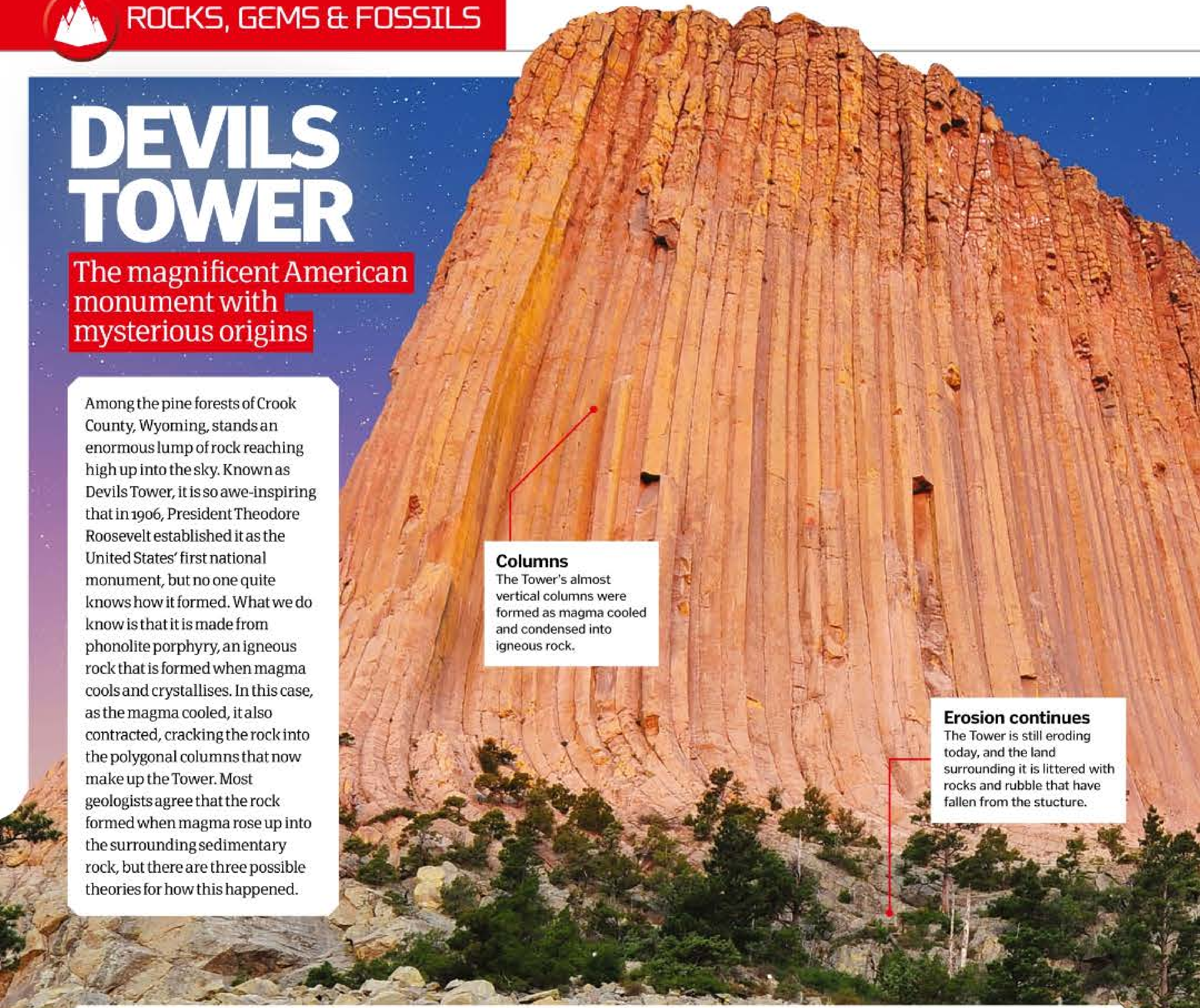
Mount Erebus is the second tallest volcano in Antarctica, and the most southerly active volcano on Earth

© Thinkstock; [illegible]; Illustration by Jon Wells

DEVILS TOWER

The magnificent American monument with mysterious origins

Among the pine forests of Crook County, Wyoming, stands an enormous lump of rock reaching high up into the sky. Known as Devils Tower, it is so awe-inspiring that in 1906, President Theodore Roosevelt established it as the United States' first national monument, but no one quite knows how it formed. What we do know is that it is made from phonolite porphyry, an igneous rock that is formed when magma cools and crystallises. In this case, as the magma cooled, it also contracted, cracking the rock into the polygonal columns that now make up the Tower. Most geologists agree that the rock formed when magma rose up into the surrounding sedimentary rock, but there are three possible theories for how this happened.

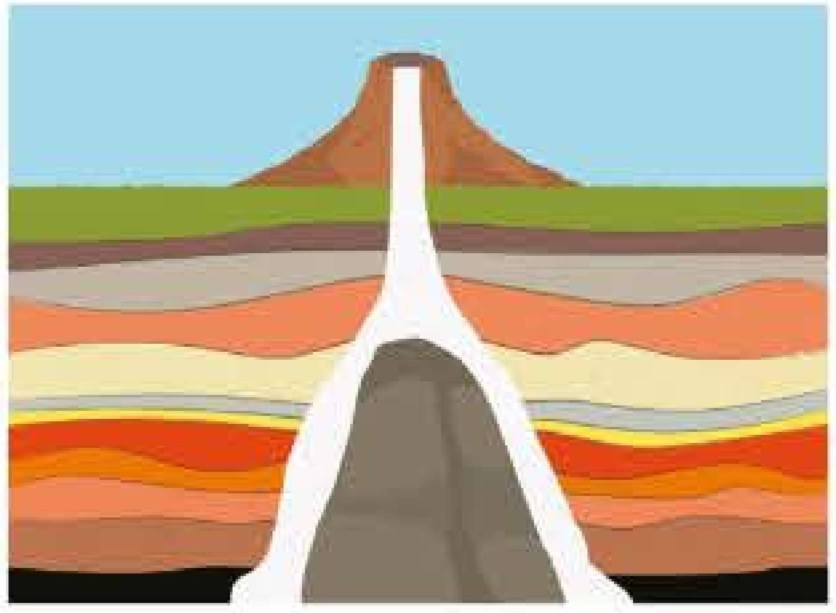


Columns
The Tower's almost vertical columns were formed as magma cooled and condensed into igneous rock.

Erosion continues
The Tower is still eroding today, and the land surrounding it is littered with rocks and rubble that have fallen from the stucture.

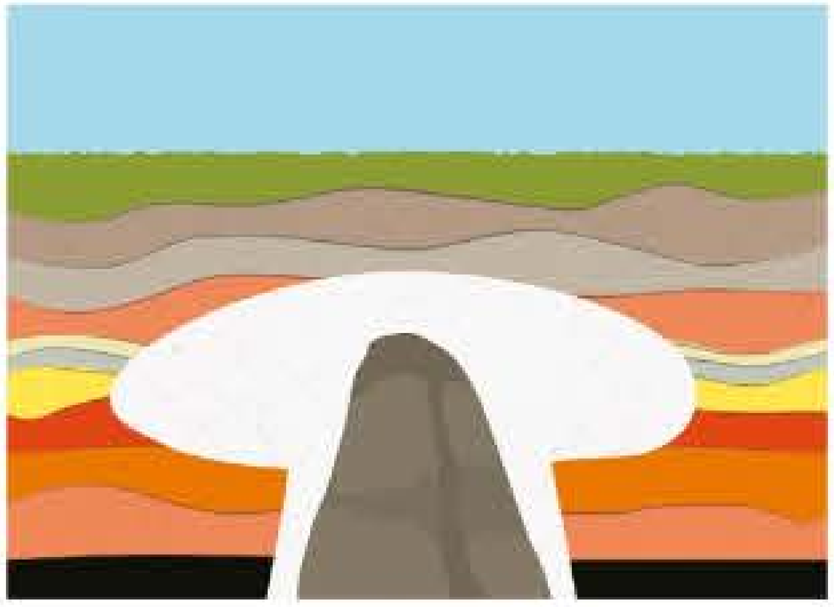
Formation theories

Three popular ideas of how Devils Tower came to be



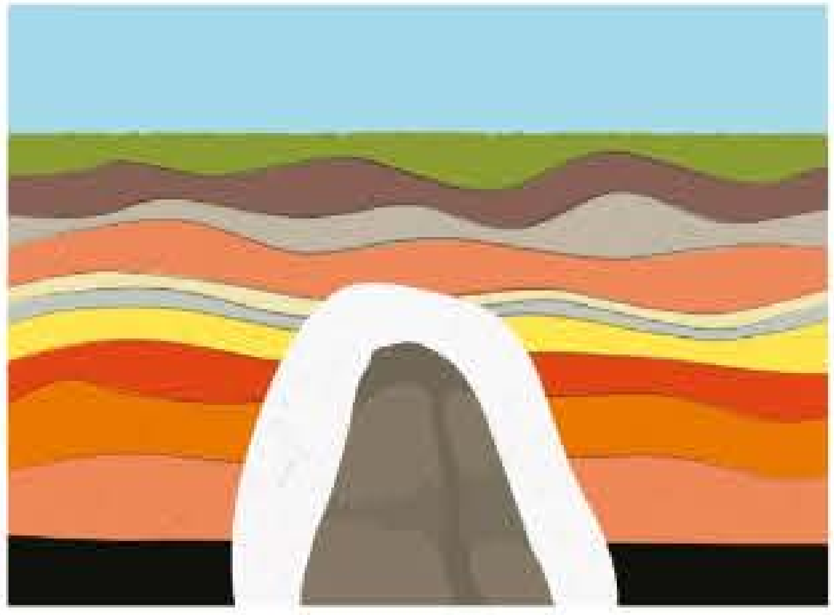
Theory 1 – Volcanic plug

The rock is the neck of an extinct volcano or a plug that lay beneath it. Although there is no evidence of volcanic activity, such as ash or lava flows, in the area, this material could have simply eroded away.



Theory 2 – Laccolith

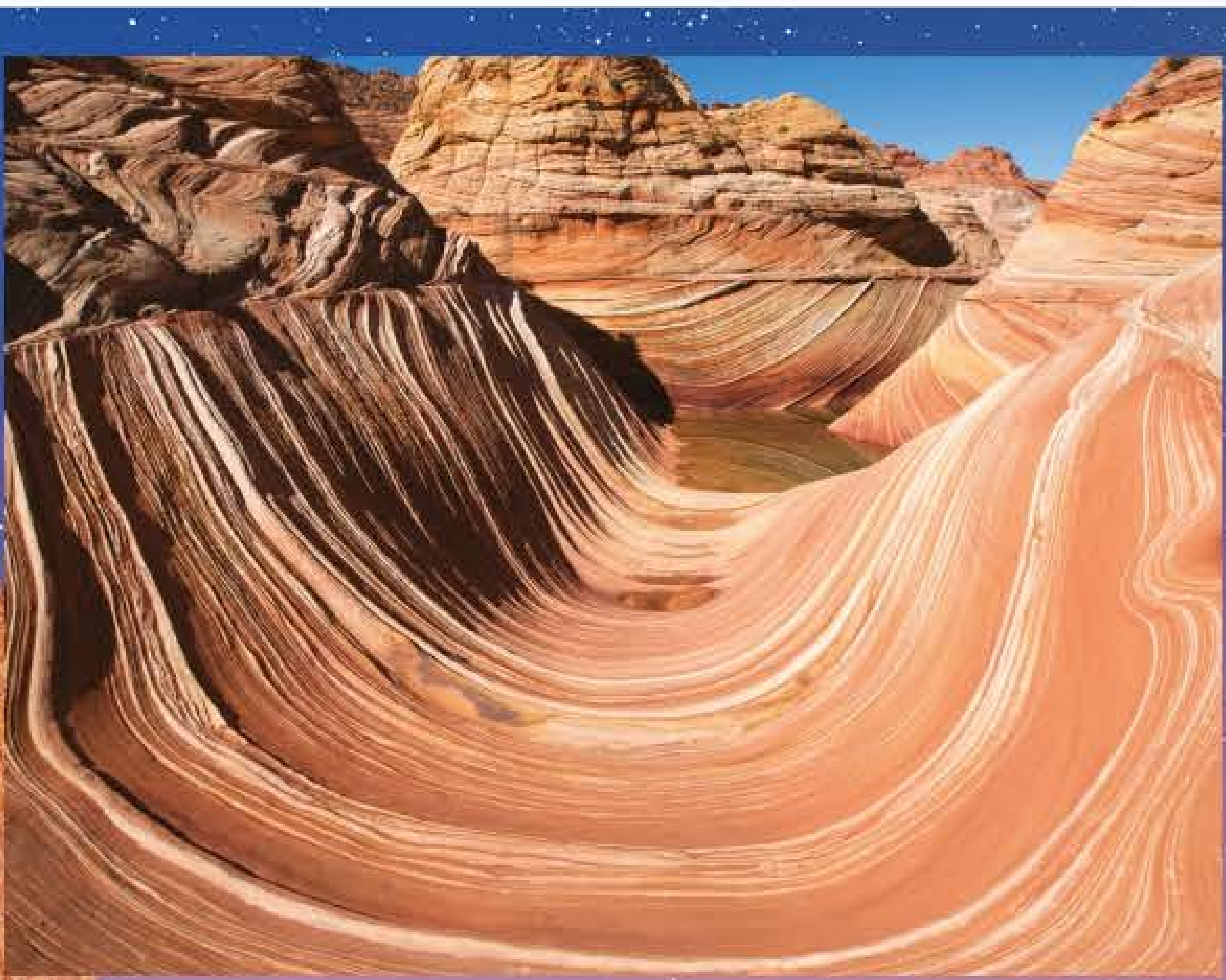
The Devils Tower is a laccolith, a large, mushroom-shaped mass of igneous rock, which spreads between the layers of sedimentary rocks beneath the Earth's surface. The rounded bulge on top has eroded away.



Theory 3 – Stock

Magma beneath the Earth's surface cooled and crystallised to form the lump of rock you can see today. Over time it was exposed by erosion wearing away the rock above it.

DID YOU KNOW? *Devils Tower is officially missing an apostrophe, as it was omitted in a proclamation signed by Roosevelt*



THE WAVE

Arizona's sweeping rock of many colours was once a dinosaur stomping ground

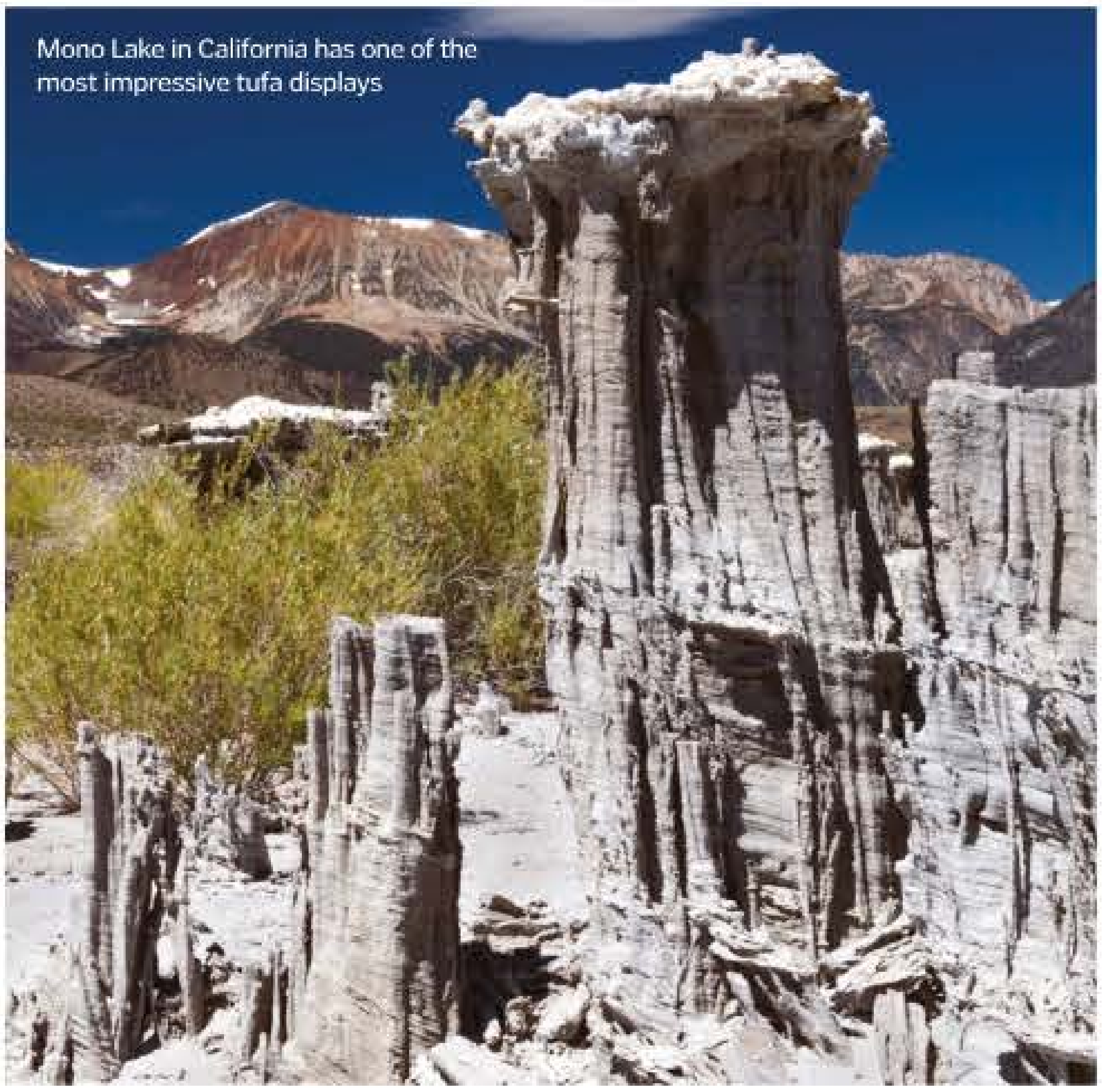
This spectacular wave structure started to form 190 million years ago when dinosaurs walked the Earth, and their footprints can still be seen in the rock today. The Wave began as sand dunes, which were compacted and solidified to become sandstone. The smooth undulating shape is the result of very slow erosion, originally caused by the flow of water, which deposited various minerals into the rock to create the colourful stripes that swirl through it. When the water dried up, wind erosion took over, and continues to carve the rock to this day.

To help protect the soft rock of the Wave, only 20 visitors are permitted each day

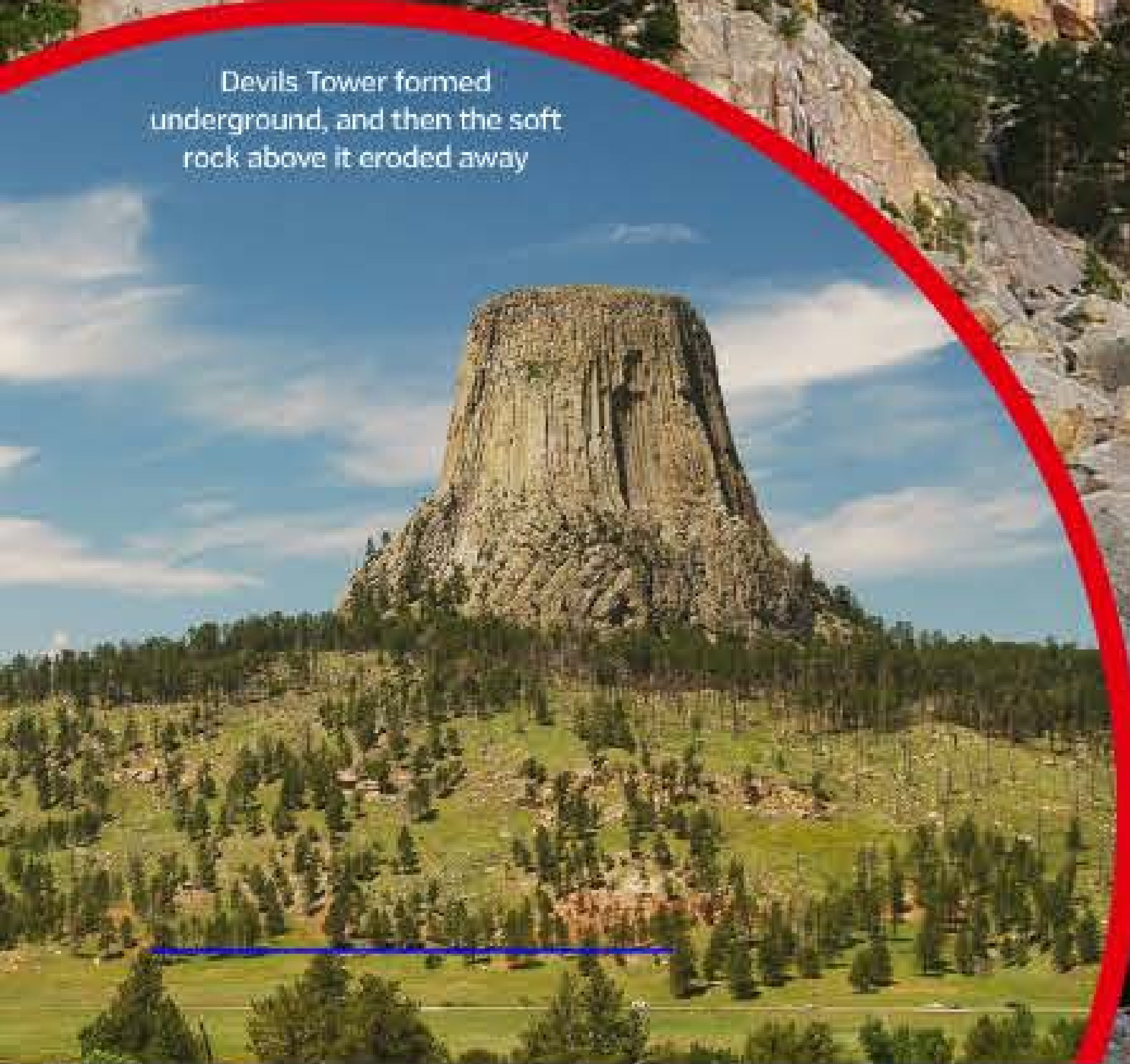
SAND TUFA

The bizarre cauliflower formations that sprout when conditions are just right

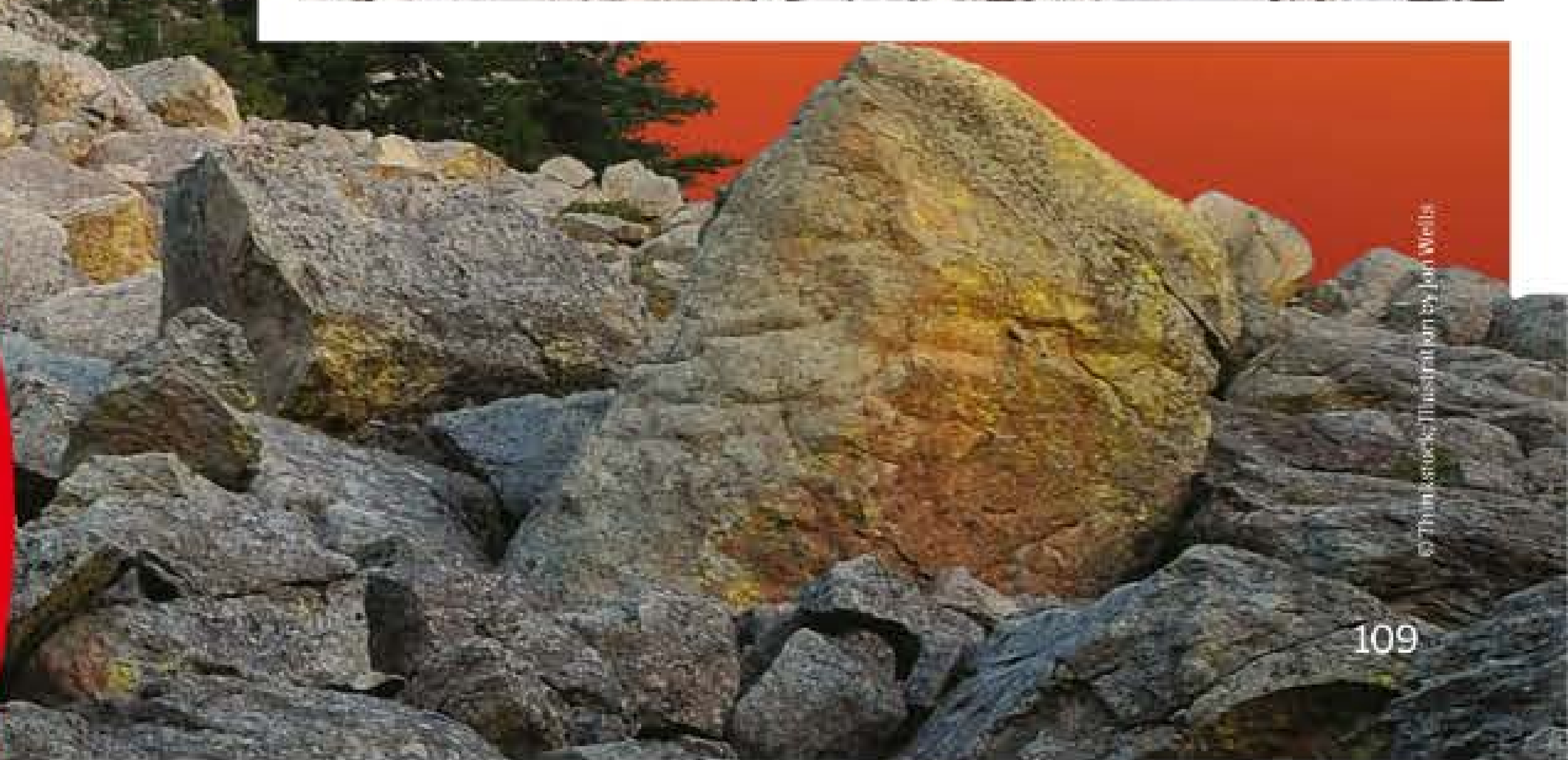
They may look like the flowering head of a popular vegetable, but these alien-like structures are actually known as tufa. They form underwater in alkaline lakes, such as California's Mono Lake, at the site of freshwater springs rich in calcium. When the calcium comes into contact with carbonates in the surrounding water, calcium carbonate forms, also known as limestone. The limestone settles on the lake bed, and as more and more is deposited, a tower begins to grow. Most of these structures remain obscured by water, but in lakes where the water levels have dropped, they become visible for all to see.



Mono Lake in California has one of the most impressive tufa displays



Devils Tower formed underground, and then the soft rock above it eroded away



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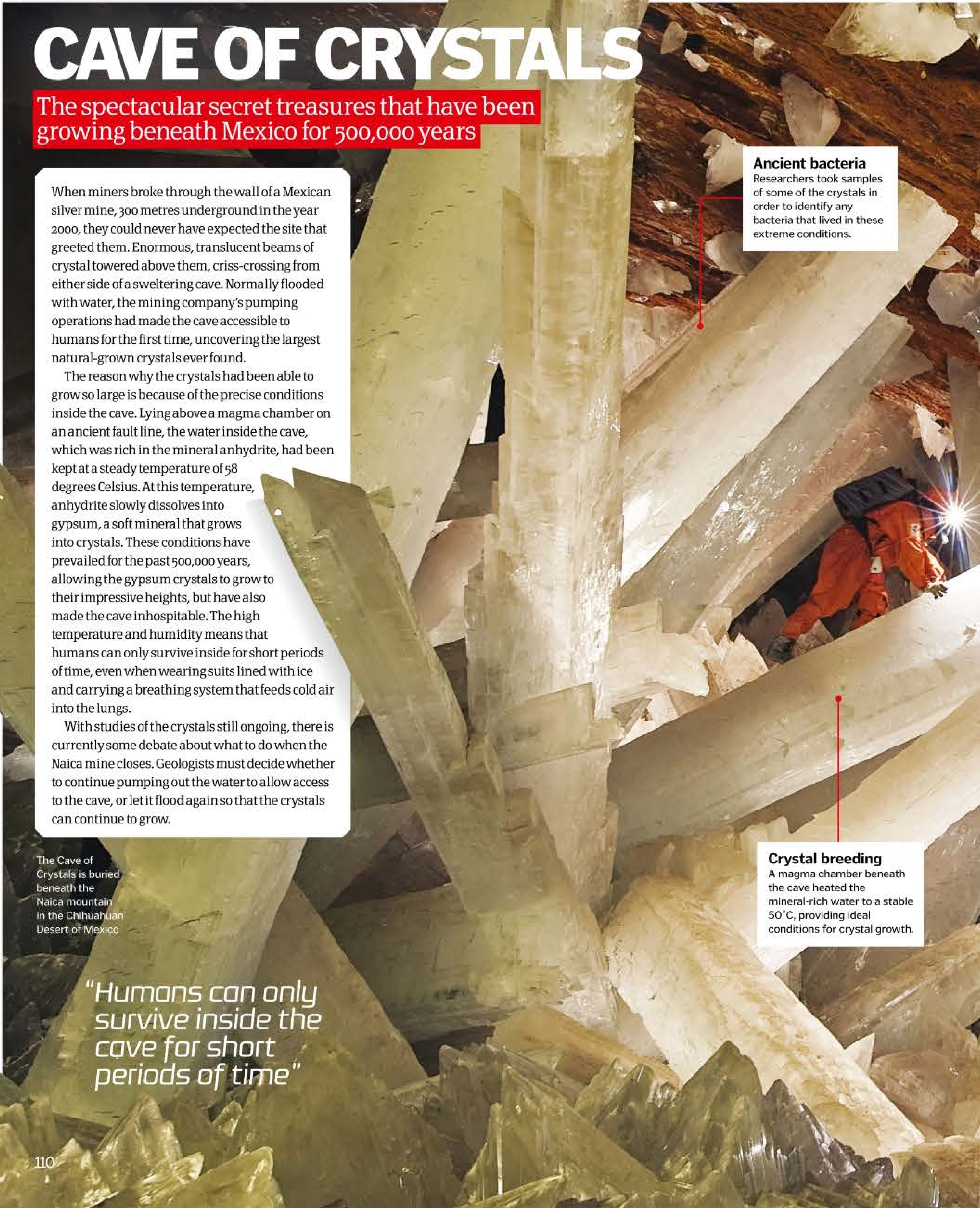
CAVE OF CRYSTALS

The spectacular secret treasures that have been growing beneath Mexico for 500,000 years

When miners broke through the wall of a Mexican silver mine, 300 metres underground in the year 2000, they could never have expected the site that greeted them. Enormous, translucent beams of crystal towered above them, criss-crossing from either side of a sweltering cave. Normally flooded with water, the mining company's pumping operations had made the cave accessible to humans for the first time, uncovering the largest natural-grown crystals ever found.

The reason why the crystals had been able to grow so large is because of the precise conditions inside the cave. Lying above a magma chamber on an ancient fault line, the water inside the cave, which was rich in the mineral anhydrite, had been kept at a steady temperature of 58 degrees Celsius. At this temperature, anhydrite slowly dissolves into gypsum, a soft mineral that grows into crystals. These conditions have prevailed for the past 500,000 years, allowing the gypsum crystals to grow to their impressive heights, but have also made the cave inhospitable. The high temperature and humidity means that humans can only survive inside for short periods of time, even when wearing suits lined with ice and carrying a breathing system that feeds cold air into the lungs.

With studies of the crystals still ongoing, there is currently some debate about what to do when the Naica mine closes. Geologists must decide whether to continue pumping out the water to allow access to the cave, or let it flood again so that the crystals can continue to grow.

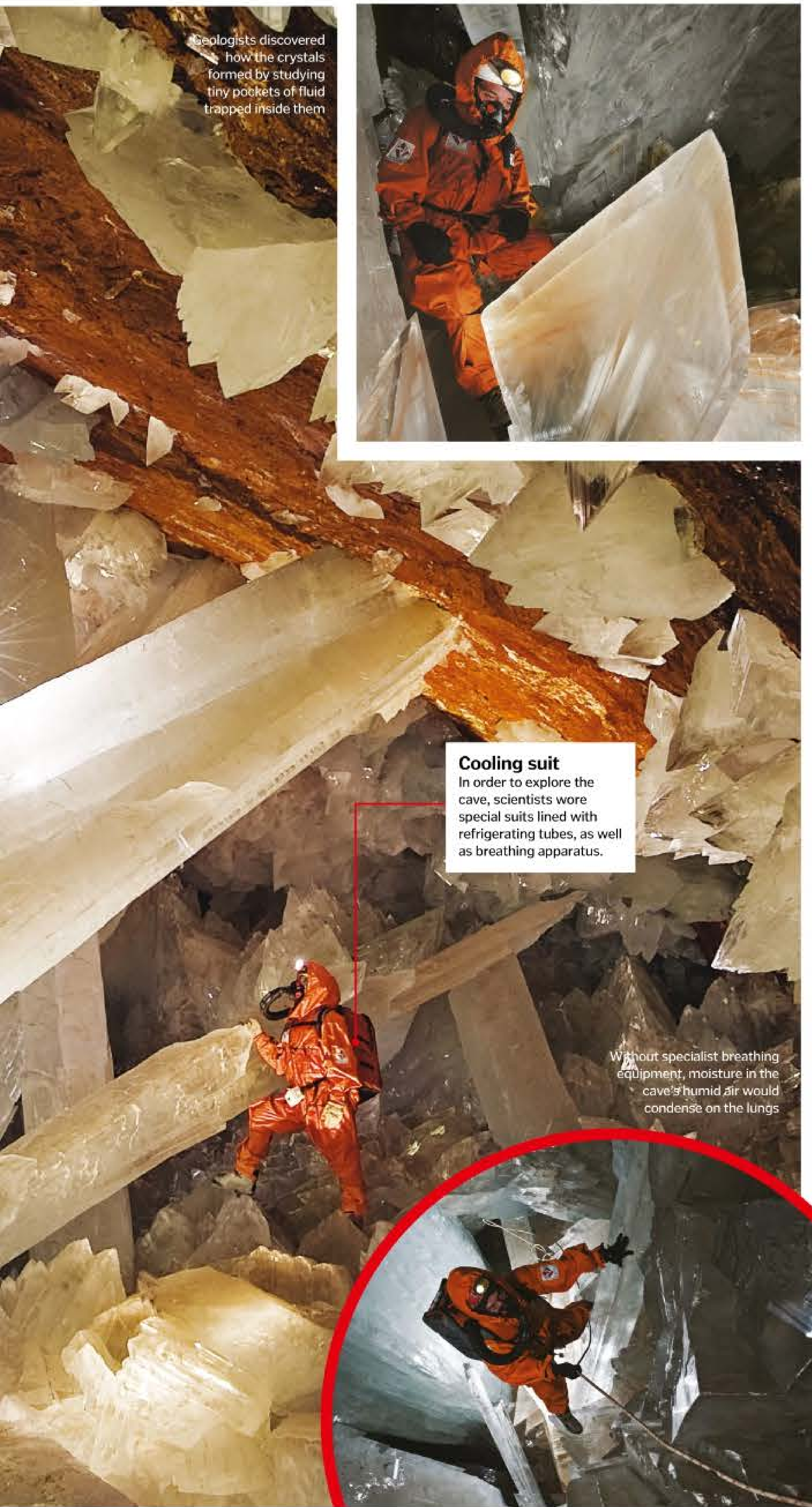


The Cave of Crystals is buried beneath the Naica mountain in the Chihuahuan Desert of Mexico

"Humans can only survive inside the cave for short periods of time"

Ancient bacteria
Researchers took samples of some of the crystals in order to identify any bacteria that lived in these extreme conditions.

Crystal breeding
A magma chamber beneath the cave heated the mineral-rich water to a stable 50˚C, providing ideal conditions for crystal growth.



Geologists discovered how the crystals formed by studying tiny pockets of fluid trapped inside them

Cooling suit
In order to explore the cave, scientists wore special suits lined with refrigerating tubes, as well as breathing apparatus.

Without specialist breathing equipment, moisture in the cave's humid air would condense on the lungs

Cave by numbers

Unbelievable stats about the deadly cave of wonders

11m
THE LENGTH OF THE TALLEST CRYSTAL, ALMOST THE HEIGHT OF THREE DOUBLE-DECKER BUSES

55 tons
THE WEIGHT OF THE LARGEST CRYSTAL, EQUIVALENT TO NINE AFRICAN ELEPHANTS

10min
The length of time you can survive in the cave without any equipment

2hrs
The length of time you can survive in the cave with proper equipment

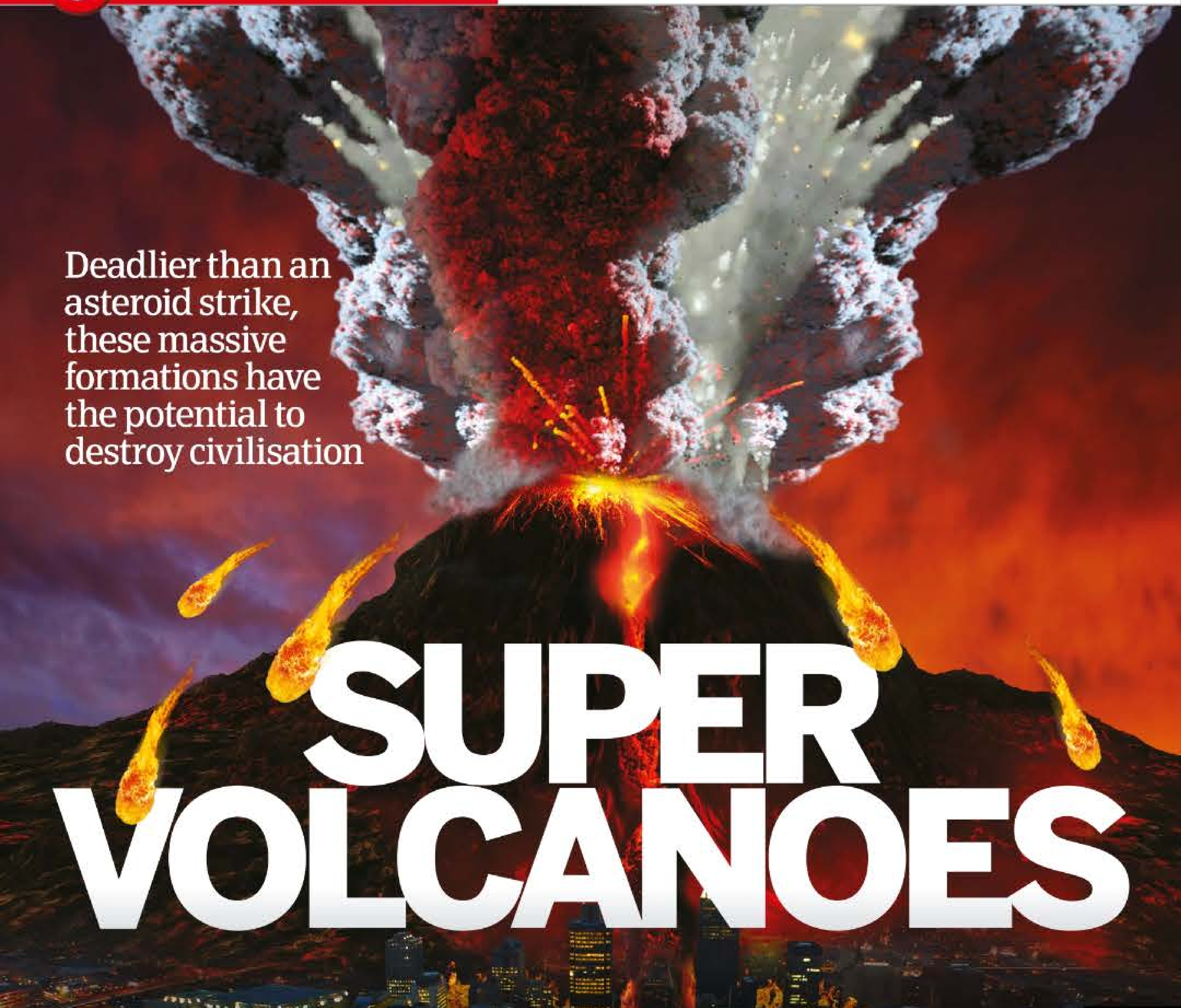
9x27m
The size of the Cave of Crystals – slightly larger than a tennis court

90-100%
HUMIDITY INSIDE THE CAVE

20 KG
Weight of the cooling suit that must be worn inside the cave

50 °C
THE TEMPERATURE INSIDE THE CAVE

© Getty



Deadlier than an asteroid strike, these massive formations have the potential to destroy civilisation

SUPER VOLCANOES

Many people will remember the airport chaos of spring 2010 when Eyjafjallajökull, one of Iceland's largest volcanoes, erupted after almost two centuries of peaceful slumber.

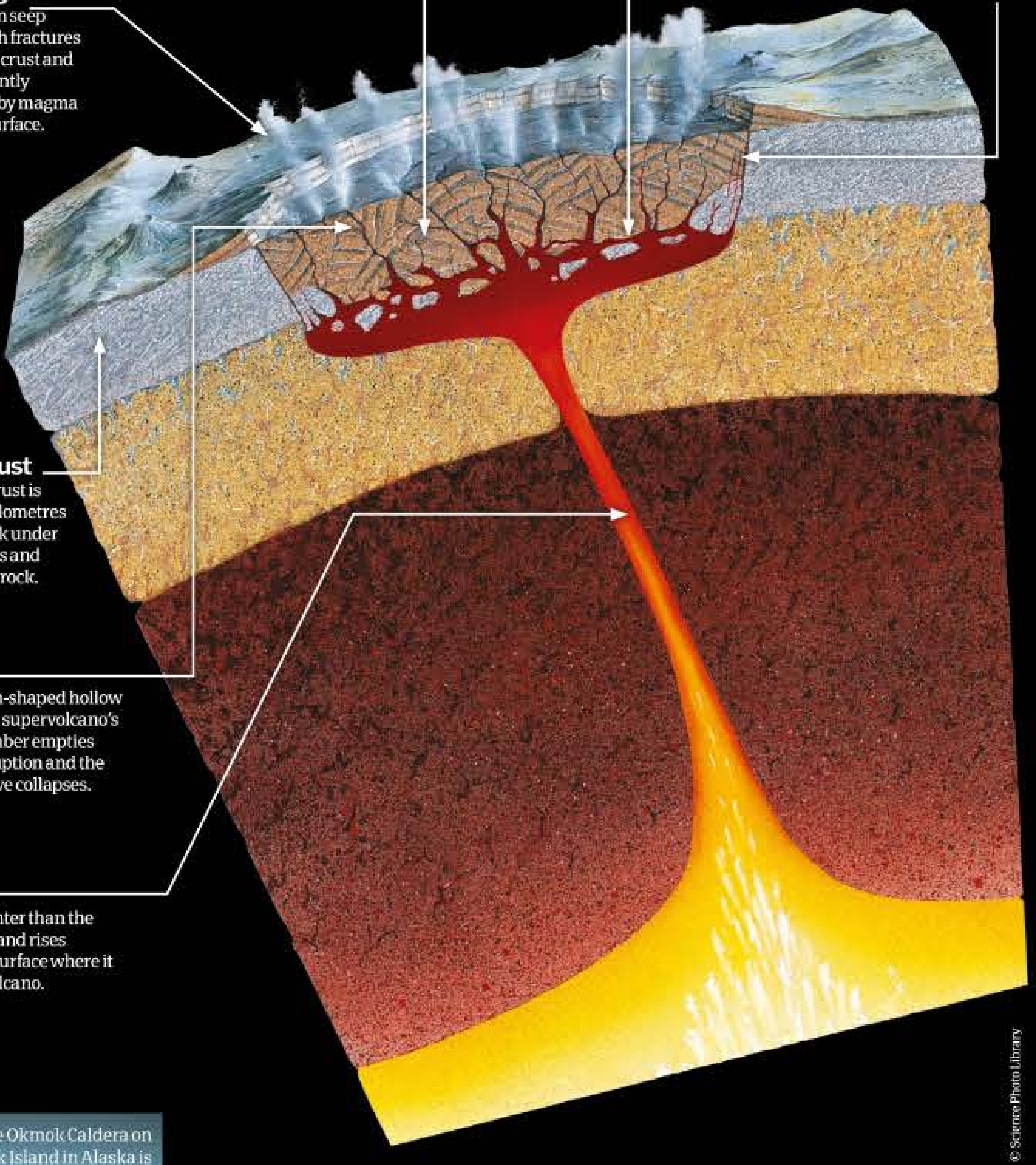
But though it might be hard to believe, considering the mammoth amount of disruption that it caused, the Icelandic eruption was tiny compared to a super-eruption's devastating power. The Eyjafjallajökull event measured a mere 4 on the Volcanic Explosivity Index (VEI), which rates the power of eruptions on an eight-point scale. A massive VEI 8 blast, on the other hand, would threaten human civilisation. Such a super-eruption would spew out more than 1,000 cubic kilometres (240 cubic miles) of ejecta – ash, gas and pumice – within days, destroying food crops, and changing the world climate for years.

A super-eruption hasn't happened in recorded history, but they occur about every 10,000-100,000 years. That's five times more often than an asteroid collision big enough to threaten humanity. Scientists say there's no evidence that a super-eruption is imminent, but humans will face nature's ultimate geological catastrophe one day.

A supervolcano is simply a volcano that's had one or more super-eruptions in its lifetime. Supervolcanoes are typically active for millions of years, but wait tens of thousands of years between major eruptions. The longer that they remain dormant, the bigger the super-eruption. They typically erupt from a wide, cauldron-shaped hollow called a caldera, although not every caldera houses a future supervolcano.

DID YOU KNOW? *Water heated under Yellowstone causes the park's many geysers*

Inside a supervolcano



Resurgent dome
Molten rock rising in the underground magma chamber pushes the overlying caldera floor upwards into a dome.

Shallow magma chamber
An underground pool of molten rock called magma, which vents to the surface as a volcanic eruption.

Ring fractures
A circular fracture running around the collapsed edge of the magma chamber through which lava often escapes.

Hot springs
Snow and rain seep down through fractures in the Earth's crust and are subsequently superheated by magma close to the surface.

Earth's crust
The Earth's crust is perhaps 56 kilometres (35 miles) thick under the continents and made of solid rock.

Caldera
This cauldron-shaped hollow forms when a supervolcano's magma chamber empties during an eruption and the rock roof above collapses.

Magma
Magma is lighter than the Earth's crust and rises towards the surface where it erupts as a volcano.

© Science Photo Library

The Okmok Caldera on Umnak Island in Alaska is 9.3km (5.8mi) wide

Predicting the next super-eruption

Volcanologists at the Yellowstone Volcanic Observatory are among those studying supervolcanoes. They hope to have decades or centuries to prepare for a super-eruption. Warning signs could include the ground bulging and cracking as hot rock muscles to the surface, an increase in small eruptions and earthquakes, and changes in the gases escaping the ground.

Scientists analyse earthquakes by measuring ground vibration with seismometers. Earthquakes often increase before eruptions as magma and gas force through underground fractures, causing rocks to break. The ground historically rises before eruptions due to upwelling magma. For example, the north flank of US volcano Mount St Helens rose by a staggering 80 metres (262 feet) in 1980.

Scientists constantly keep track of Earth movements using networks of satellite GPS receivers. Like GPS in cars, these monitor the receiver's location on the ground. Another satellite technology, InSAR, measures ground movement over large areas once or twice annually.

8. CALDERA FORMS

DAYS

The rock cylinder inside the ring fractures and plunges into the emptied magma chamber. Gas and lava spurt from the fractures.

7. DEADLY CLOUDS

DAYS

The fractures join into a ring of erupting vents. Toxic ash and fragment clouds race downhill at snow avalanche speed.

6. SUPER-ERUPTION

HOURS TO DAYS

The expanding gases act like bubbles of pop in a shaken bottle, flinging lava and rock high into the atmosphere.

5. MAGMA CHAMBER RUPTURES

HOURS TO DAYS

Vertical fractures in the swollen crust breach the magma chamber, allowing pressurised, gas-filled magma to escape to the surface as lava.

4. WARNING SIGNS INCREASE

WEEKS TO CENTURIES

Warning signs of a super-eruption may include swarms of earthquakes and the ground rapidly swelling up like baking bread.

3. MAGMA CHAMBER EXPANDS

TENS OF THOUSANDS OF YEARS

Supervolcano magma chambers can grow for tens of thousands of years because they are surrounded by flexible hot rock.

2. PRESSURE BUILDS

TENS OF THOUSANDS OF YEARS

As magma accumulates in a chamber, the pressure builds and the cavity expands. Fractures begin to form in the chamber roof.

1. MAGMA RISES

TIME: MILLIONS OF YEARS

Magma forms when rock deep in the Earth liquefies and pushes through the solid crust towards the surface.

COUNTDOWN TO ERUPTION

This artist's illustration reveals the smoke and ash that could result from a supervolcanic eruption at Yellowstone

The supervolcano simmering under Yellowstone National Park in the USA is probably the world's most studied, but super-eruptions occur so rarely that they remain a mystery. We know of 42 VEI 7 and VEI 8 eruptions in the last 36 million years, but much of the debris from these ancient super-eruptions has worn away. Eruptions like these take place at irregular intervals and scientists are unsure what triggers them.

Supervolcanoes, like all volcanoes, occur where molten or partly molten rock called magma forms and erupts to the Earth's surface. All supervolcanoes break through the thick crust that forms the continents. The Yellowstone caldera sits on a hot spot, a plume of unusually hot rock in the solid layer called the mantle that lies below the Earth's crust. Blobs of molten mantle rise from the hot spot towards the surface and melt the crustal rocks.

Other supervolcanoes like Lake Toba in Sumatra, Indonesia, lie on the edges of the jigsaw of plates that make up the Earth's crust. Near Sumatra, the plate carrying the Indian Ocean is being pushed underneath the crustal plate carrying Europe. As it descends, the ocean plate melts to form magma.

Vast quantities of magma are needed to fuel a super-eruption. Some scientists believe that supervolcanoes are 'super' because they have gigantic, shallow magma chambers that can hold volumes of up to 15,000 cubic kilometres (3,600 cubic miles) and grow for thousands of years. Magma chambers are underground pools of accumulated magma that erupt through cracks to the surface. Volcanoes with smaller chambers expel magma before enough pressure builds for a supersized event.

Some scientists speculate that hot, flexible rocks surround supervolcano magma chambers, allowing them to swell to accommodate more magma. The rocks are kept malleable by blobs of magma repeatedly welling up from below.

A super-eruption starts when the pressurised magma explodes through fractures in the chamber roof. The eruption is violent because supervolcano magma is rich in trapped gas bubbles, which expand and burst as it abruptly depressurises; the eruption is akin to uncorking a champagne bottle. The magma is also sticky and unable to flow easily because it's made partly from melted continental crust. This is in contrast to a volcano such as Mauna Loa in Hawaii, which gently pours out lava because its magma is fluid and contains little gas.

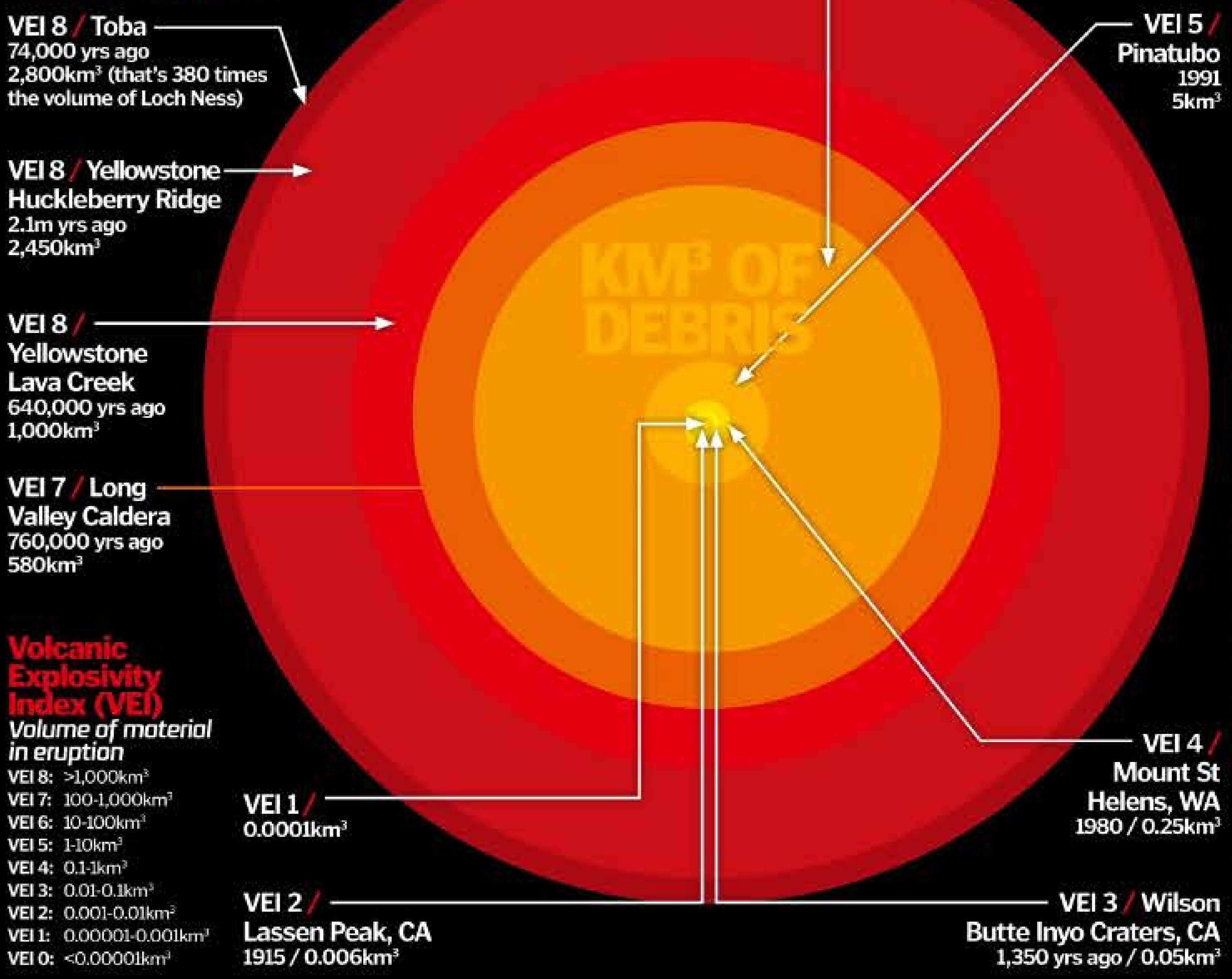
Hot fragments and gas soar to heights of more than 35 kilometres (22 miles) and spread in the atmosphere. Some of the fragments drift down and blanket the ground like snow. Other hot fragments rush downhill for hundreds of square kilometres at speeds exceeding 100 kilometres per hour (62 miles per hour) as toxic, ground-hugging pyroclastic flows. The magma chamber rapidly drains during the super-eruption, causing the roof above to sink into the empty space to (re-)form a caldera.

The fallout following a super-eruption

A supervolcano erupting today could threaten human civilisation. Clouds of molten rock and iridescent gas travelling three times faster than motorway cars would obliterate everything within 100 kilometres (60 miles) of the blast. Dust would spread thousands of kilometres, blotting out the Sun. People's unprotected eyes, ears and noses would fill with needle-like ash, which can pop blood vessels in the lungs and kill by suffocation.

Up to 0.5 metres (1.6 feet) of ash could rain down each hour, collapsing roofs, poisoning water supplies and halting transport by clogging car and aircraft engines; just a few centimetres of ash can disrupt agriculture. The 1815 eruption of Indonesia's Mount Tambora caused the 'year without a summer' when European harvests failed, bringing famine and economic collapse. Financial markets could be disrupted and countries swamped by refugees. Some scientists say a Yellowstone super-eruption could render one-third of the United States uninhabitable for up to two years.

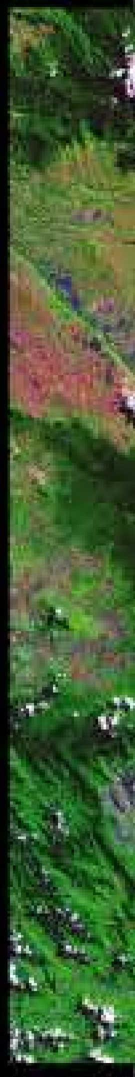
Comparison of eruption volumes


VEI 8 / Toba
74,000 yrs ago
2,800km³ (that's 380 times the volume of Loch Ness)
VEI 8 / Yellowstone Huckleberry Ridge
2.1m yrs ago
2,450km³
VEI 8 / Yellowstone Lava Creek
640,000 yrs ago
1,000km³
VEI 7 / Long Valley Caldera
760,000 yrs ago
580km³
VEI 7 / Yellowstone Mesa Falls
1.3m yrs ago
280km³
VEI 5 / Pinatubo
1991
5km³
KM³ OF DEBRIS
VEI 4 / Mount St Helens, WA
1980 / 0.25km³
VEI 3 / Wilson Butte Inyo Craters, CA
1,350 yrs ago / 0.05km³
VEI 2 / Lassen Peak, CA
1915 / 0.006km³
VEI 1 / 0.0001km³

Volcanic Explosivity Index (VEI)

Volume of material in eruption

VEI 8:	>1,000km^3
VEI 7:	100-1,000km^3
VEI 6:	10-100km^3
VEI 5:	1-10km^3
VEI 4:	0.1-1km^3
VEI 3:	0.01-0.1km^3
VEI 2:	0.001-0.01km^3
VEI 1:	0.00001-0.001km^3
VEI 0:	<0.00001km^3



VOLCANOES VS SUPERVOLCANOES

The explosive battle

	TYPICAL VOLCANO	TYPICAL SUPERVOLCANO
FOOTPRINT	Volcanoes vary, but a typical shield volcano might be 5.6km (3.5mi) across. The crater – equivalent to a caldera – of Mount St Helens, USA, is about 3.2km (2mi) wide.	Bigger calderas produce larger eruptions, meaning most supervolcanoes cover vast areas. Lake Toba is 90km (56mi) long and lies in such a caldera.
HEIGHT	Normal volcanoes are cone-shaped mountains perhaps 1km (3,280ft) high. Mount St Helens, for example, stands 635m (2,084ft) above its crater floor.	Supervolcanoes have 'negative' topography: they erupt from smouldering pits. Lake Toba, which lies in a supervolcano caldera, is over 0.5km (0.3mi) deep.
VOLUME	Typical volcanoes have smaller magma chambers. The magma chamber of Mount St Helens, for example, has a volume of just 10-20km^3 (2.4-4.8mi^3).	Yellowstone's magma chamber and caldera are similar in width. The chamber is 60 x 40km (37 x 25mi) wide, and 5-16km (3-10mi) below the surface.
EJECTA	Even huge volcanoes produce comparatively little debris; eg Yellowstone's super-eruptions were up to 2,500 times bigger than the 1980 St Helens blast.	Super-eruptions eject more than 1,000km^3 (240mi^3) of debris. They also spew at least 10^{12} tons of magma: more than the mass of 50 billion cars.
DAMAGE	A few eruptions, like Mt Tambora in 1815, changed global climate, but most of the 20 volcanoes erupting as you read this affect only their immediate vicinity.	A Yellowstone eruption could lower Earth's average temperature by 10°C (18°F) for ten years. Within 1,000km (621mi) of the blast, 90 per cent of people could die.

A super-eruption took place in Sumatra 74,000 years ago, forming the planet's largest volcanic lake in the process: Lake Toba

A satellite view of Yellowstone National Park, which is positioned above a hot spot in the Earth's crust

© NASA

Geysers like Old Faithful at Yellowstone are heated by the supervolcano which lies beneath

Yellowstone's restless giant

Beneath Yellowstone National Park bubbles an active supervolcano. A magma chamber, lying as close as eight kilometres (five miles) to the surface in places, fuels the park's 10,000 jewel-coloured hot springs, gurgling mud pools, hissing steam vents and famous geysers like Old Faithful. The 8,897-square-kilometre (3,435-square-mile) park includes the volcano's caldera, which spans 4,400 square kilometres (1,750 square miles); that's big enough to cover the emirate of Dubai.

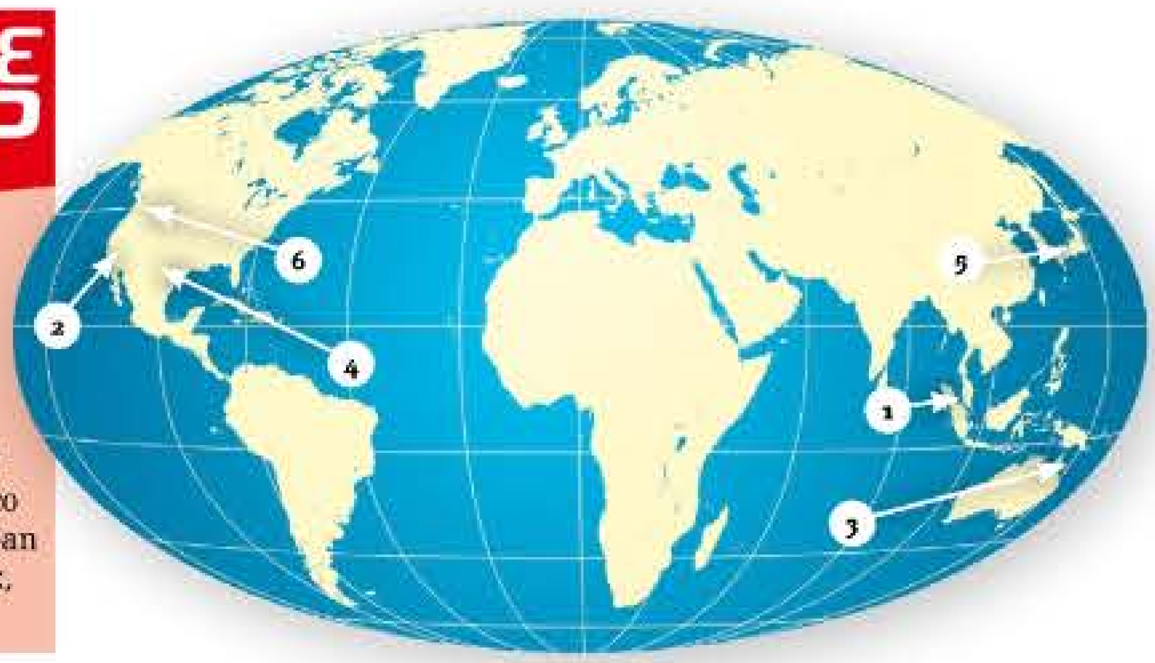
The supervolcano is fuelled by a 'hot spot', a plume of hot rock rising from hundreds of kilometres below the Earth's surface. Hot spots act like gigantic Bunsen burners, driving catastrophic eruptions by melting the rocks above them. Scientists remain uncertain why hot spots form; they're not found at the edge of Earth's crustal plates and most volcanic activity happens where these plates jostle against one another. Since the hot spot formed around 17 million years ago, it has produced perhaps 140 eruptions. The North American crustal plate has slid southwest over the stationary hot spot like a belt on a conveyor leaving a 560-kilometre (350-mile) string of dead calderas and ancient lava flows trailing behind.

There have been three super-eruptions since Yellowstone moved over the hot spot: 2.1 million, 1.3 million and 640,000 years ago. Each eruption vented enough magma from the volcano's storage reservoir to collapse the ground above into a caldera. The first and largest eruption created the Huckleberry Ridge Tuff, more than 2,450 cubic kilometres (588 cubic miles) of volcanic rock made of compacted ash. The eruption blasted a huge caldera perhaps 80 x 65 kilometres (50 x 40 miles) in area and hundreds of metres deep across the boundary of today's national park. The most recent caldera-forming eruption blanketed much of North America in ash and created today's Yellowstone Caldera. Hot gas and ash swept across an area of 7,770 square kilometres (3,000 square miles).

ON THE MAP

Six known supervolcanoes

1. Lake Toba, Sumatra, Indonesia
2. Long Valley, California
3. Lake Taupo, New Zealand
4. Valles Caldera, New Mexico
5. Aira Caldera, southern Japan
6. Yellowstone National Park, United States



What is lava?

Take a closer look at the molten material ejected by volcanoes

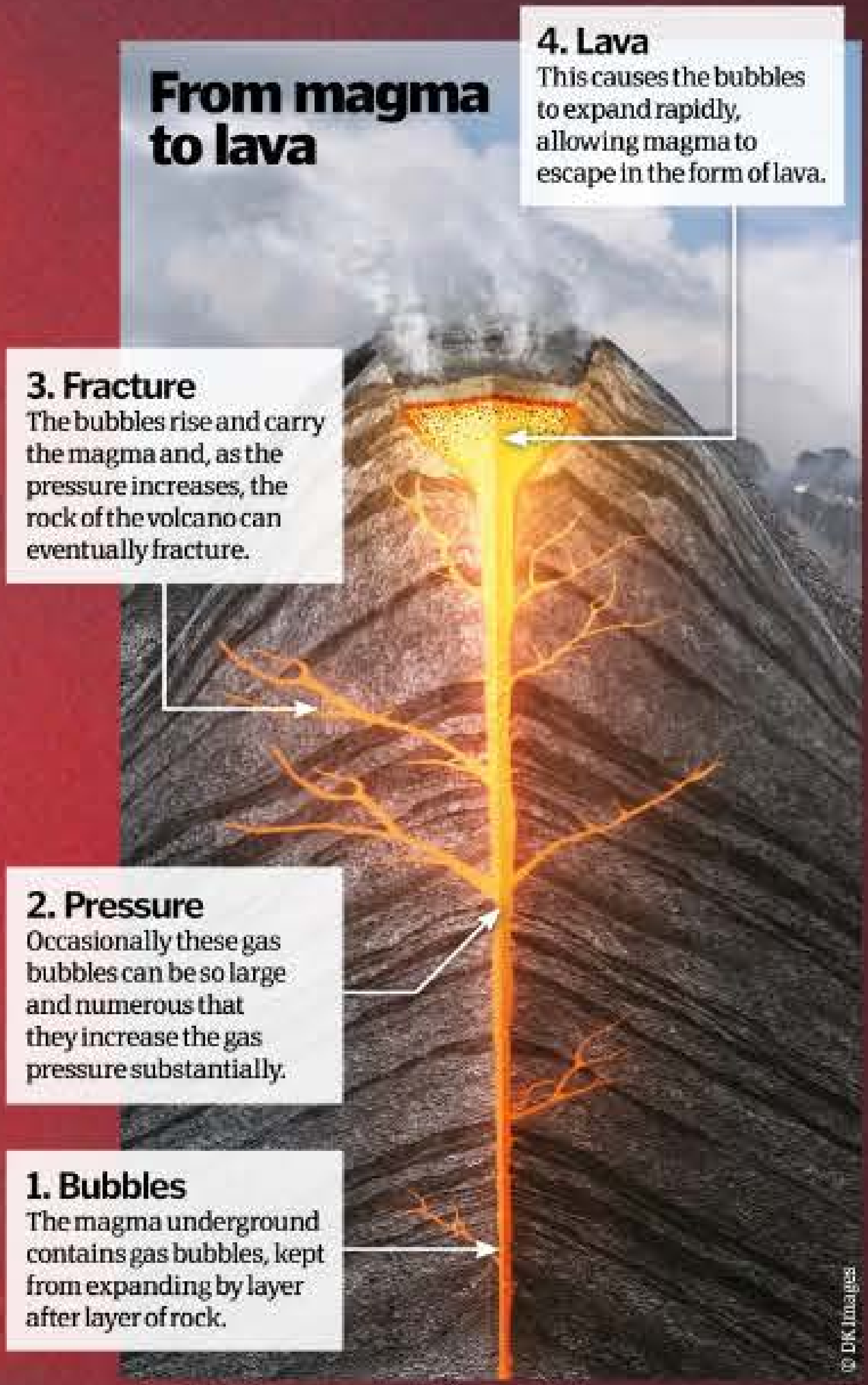
Beneath the Earth flows molten rock known as magma. When a volcano erupts, the resulting explosion shoots this magma out into the atmosphere. At this point the magma becomes known as lava. There is no major difference between magma and lava; the terms merely distinguish whether the molten rock is beneath or above the surface. Caused by gas pressure under the surface of the Earth, a giant volcanic eruption can be incredibly powerful with lava shooting up to 600 metres (2,000 feet) into the air.

Lava can reach temperatures of 700-1,200°C (1,300-2,200°F) and varies in colour from bright orange to brownish red, hottest to coldest, respectively. This viscous liquid can range from the consistency of syrup to extremely stiff, with little or no flow apparent. This is regulated by the amount of silica in the lava, with higher levels of the mineral resulting in a higher viscosity. When lava eventually cools and solidifies it forms igneous rock.

Inside lava are volcanic gases in the form of bubbles, which develop underground inside the magma. When the lava erupts from inside the volcano, it is full of a slush of crystalline minerals (such as olivine). Upon exposure to air the liquid freezes and forms volcanic glass. Different types of lava have different chemical compositions, but most have a high percentage of silicon and oxygen in addition to smaller amounts of elements such as magnesium, calcium and iron.

© Science Photo Library

DID YOU KNOW? *The fastest recorded lava flow is 60km/h (40mph) at a stratovolcano that erupted in DR Congo in 1977*



From magma to lava

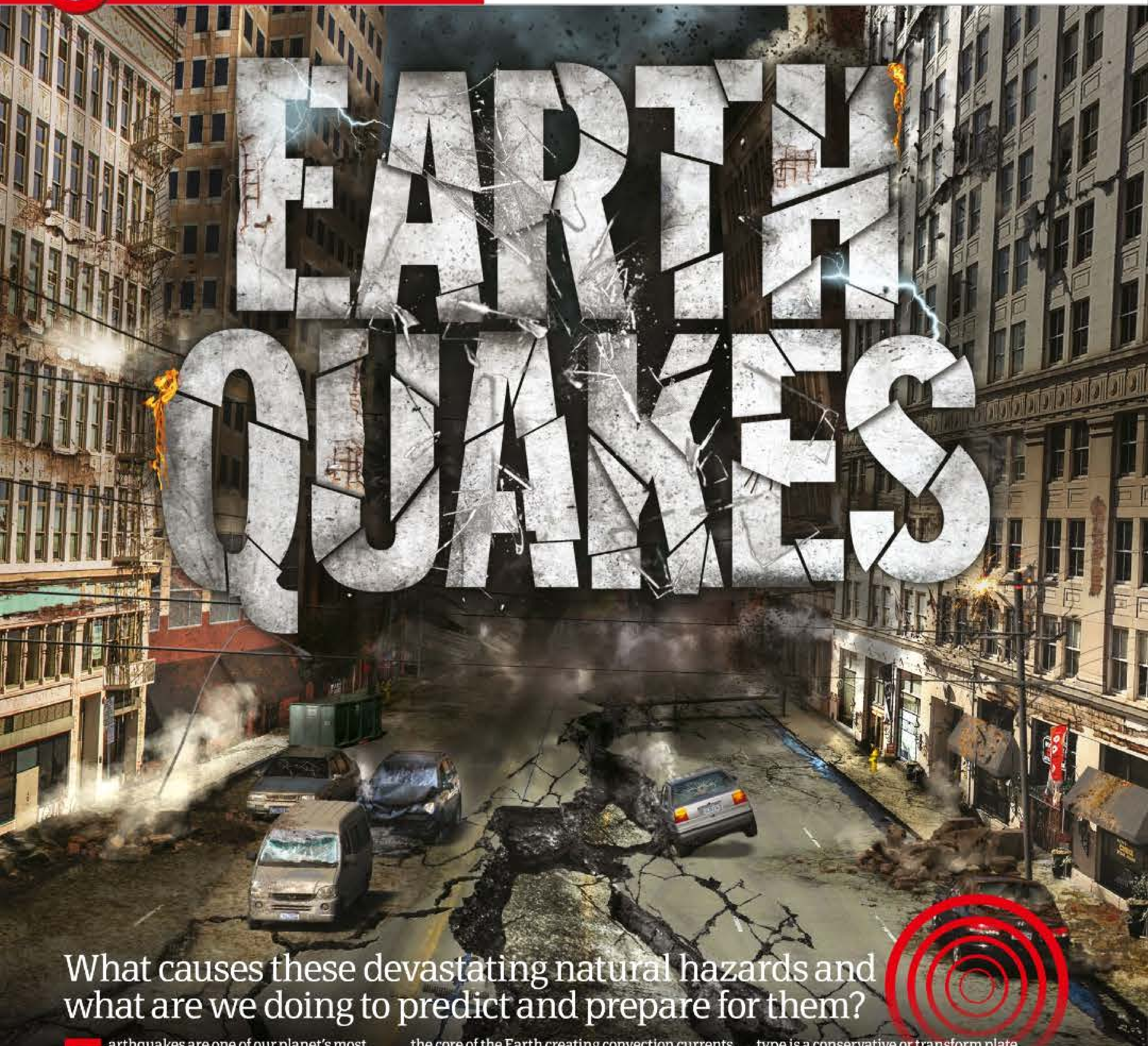
1. Bubbles
The magma underground contains gas bubbles, kept from expanding by layer after layer of rock.

2. Pressure
Occasionally these gas bubbles can be so large and numerous that they increase the gas pressure substantially.

3. Fracture
The bubbles rise and carry the magma and, as the pressure increases, the rock of the volcano can eventually fracture.

4. Lava
This causes the bubbles to expand rapidly, allowing magma to escape in the form of lava.

© DK Images



EARTHQUAKES

What causes these devastating natural hazards and what are we doing to predict and prepare for them?

Earthquakes are one of our planet's most destructive natural hazards, with the ability to flatten entire cities, trigger enormous tsunamis that wash away everything in their path, and cause a devastating loss of life.

Part of an earthquake's immense power lies in its unpredictability, as a huge quake can strike with very little warning, giving those nearby no time to get to safety. Though we don't know when they will occur, we can predict where, thanks to our knowledge of plate tectonics.

The thin top layer of the Earth, known as the crust, is divided into several plates that are constantly moving. This is caused by heat from the core of the Earth creating convection currents in the mantle just below the crust, which shifts the plates in different directions.

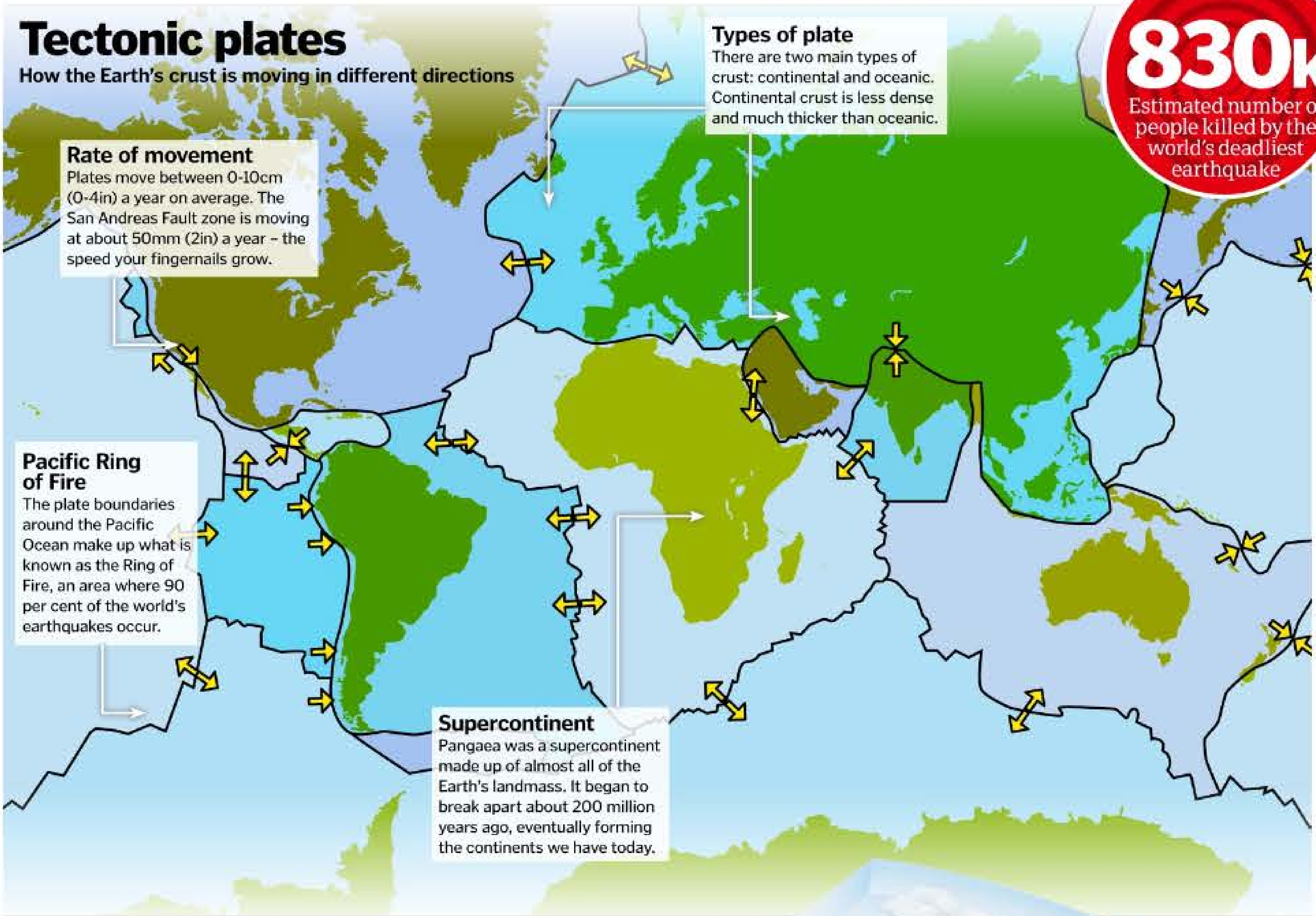
As the plates move, they collide, split apart or slide past each other along the plate boundaries, creating faults where the majority of earthquakes occur. At divergent or constructive plate boundaries the plates are moving apart, causing normal faults that form rift valleys and ocean ridges. When plates move toward each other along convergent or destructive plate boundaries, they create a reverse or thrust fault, either colliding to form mountains or sliding below the other in a process known as subduction. The third type is a conservative or transform plate boundary, and involves the two parallel plates sliding past each other to create a strike-slip fault.

Being able to identify these fault lines tells us where earthquakes are most likely to occur, giving the nearby towns and cities the opportunity to prepare. Although the secondary effects of an earthquake, such as landslides and fires from burst gas lines, can be fatal, the main cause of death and destruction during earthquakes is usually the collapse of buildings. Therefore, particularly in developed parts of the world, structures near to fault lines are built or adapted to withstand violent shock waves. The

DID YOU KNOW? *There are 500,000 earthquakes in the world each year, but only 100,000 can be felt – 100 of them cause damage*

Tectonic plates

How the Earth's crust is moving in different directions



Rate of movement
Plates move between 0-10cm (0-4in) a year on average. The San Andreas Fault zone is moving at about 50mm (2in) a year – the speed your fingernails grow.

Types of plate
There are two main types of crust: continental and oceanic. Continental crust is less dense and much thicker than oceanic.

Pacific Ring of Fire
The plate boundaries around the Pacific Ocean make up what is known as the Ring of Fire, an area where 90 per cent of the world's earthquakes occur.

Supercontinent
Pangaea was a supercontinent made up of almost all of the Earth's landmass. It began to break apart about 200 million years ago, eventually forming the continents we have today.

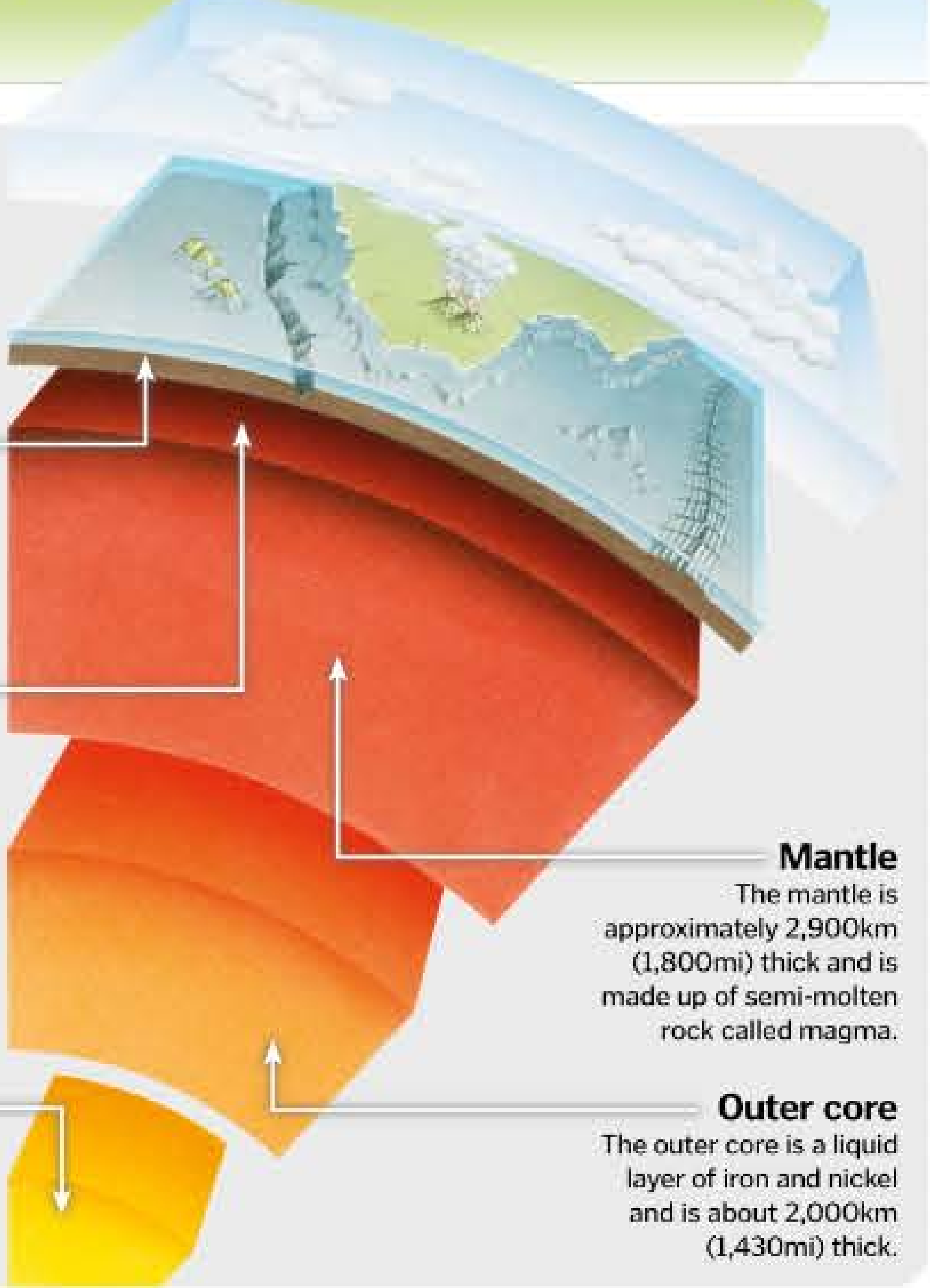
830k
Estimated number of people killed by the world's deadliest earthquake

surrounding population will usually carry out regular earthquake drills, such as The Great California ShakeOut, that gives people a chance to practise finding cover when a quake eventually hits. Unfortunately, many poorer areas cannot afford to be so well prepared, and so when an earthquake strikes, the resulting destruction is often even more devastating and the death toll is usually much higher.

However, our knowledge of how earthquakes happen and the development of new technologies are helping us to find potential methods for predicting when and where the next one will strike. Scientists can currently make general guesses about when an earthquake may occur by studying the history of seismic activity in the region and detecting where pressure is building along fault lines, but this only provides very vague results so far. The ultimate goal is to be able to reliably warn people of an imminent earthquake early enough for them to prepare and minimise the loss of life and damage of property. Until then, being under the constant threat of an impending earthquake is unfortunately part of everyday life for those living along the Earth's constantly active fault lines.

The Earth's structure

Cut through the different layers of our planet



Crust
The crust is the rocky outer layer of the Earth and is 40km (25mi) thick on average.

Lithosphere
The lithosphere, which is about 100km (62mi) deep in most places, includes the harder upper portion of the mantle and the crust.

Mantle
The mantle is approximately 2,900km (1,800mi) thick and is made up of semi-molten rock called magma.

Inner core
The inner core is made of solid nickel and iron, with temperatures of up to 5,500°C (9,930°F).

Outer core
The outer core is a liquid layer of iron and nickel and is about 2,000km (1,430mi) thick.

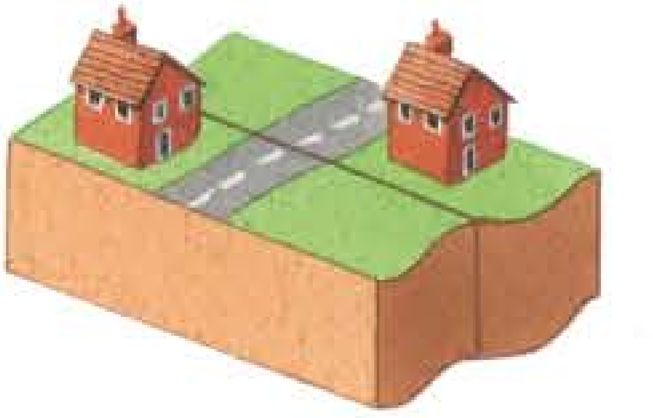
Anatomy of an earthquake

How earthquakes are caused and shake the ground beneath our feet

Earthquakes are caused by the build-up of pressure that is created when tectonic plates collide. Eventually the plates slip past each other and a huge amount of energy is released, sending seismic waves through the ground. The point at which the fracture occurs is often several kilometres underground and is known as the focus or hypocentre. The point directly above it on the surface is the epicentre, and this is where most of the damage is caused. Earthquakes have different characteristics depending on their type of fault line, but when they occur underwater, they can sometimes trigger enormous destructive waves called tsunamis.

How earthquakes occur

The build-up of pressure that causes the ground to move and shake

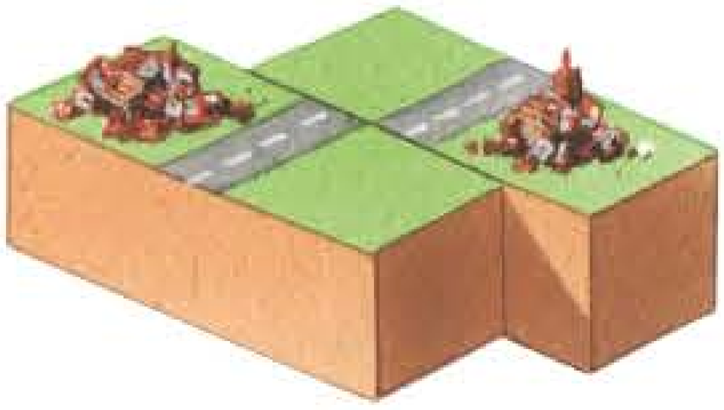


Friction causes pressure

As the tectonic plates are pushed past or into each other, friction prevents them from moving and causes a build-up of immense pressure.

Energy is released

When the pressure finally overcomes the friction, the plates will suddenly fracture and slip past each other, releasing energy and causing seismic waves.

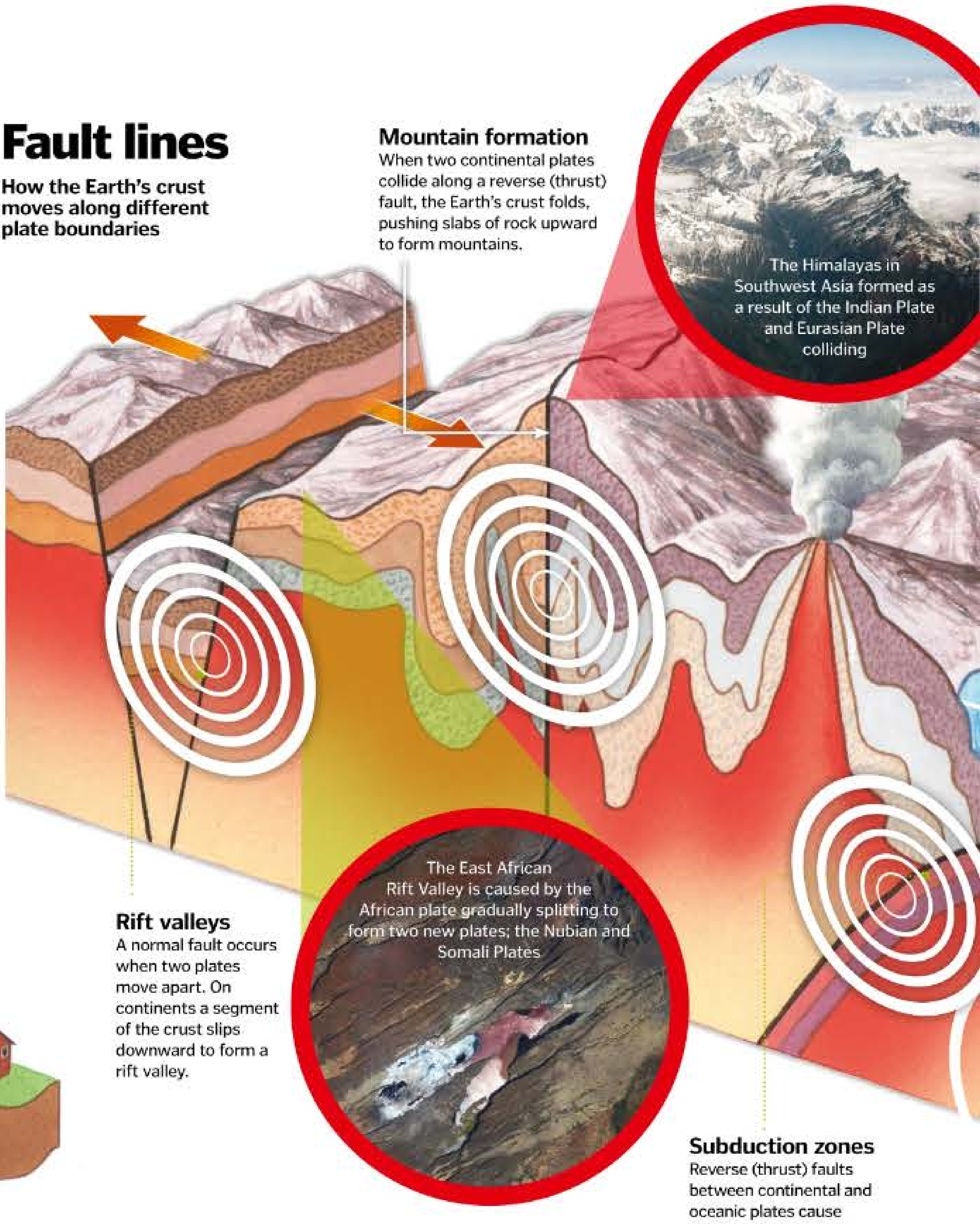


The process starts again

Once the energy has been released, the plates will assume their new position and the process will begin all over again.

Fault lines

How the Earth's crust moves along different plate boundaries



Mountain formation

When two continental plates collide along a reverse (thrust) fault, the Earth's crust folds, pushing slabs of rock upward to form mountains.

The Himalayas in Southwest Asia formed as a result of the Indian Plate and Eurasian Plate colliding

Rift valleys

A normal fault occurs when two plates move apart. On continents a segment of the crust slips downward to form a rift valley.

The East African Rift Valley is caused by the African plate gradually splitting to form two new plates; the Nubian and Somali Plates

Subduction zones

Reverse (thrust) faults between continental and oceanic plates cause subduction, causing the higher-density oceanic plate to sink below the continental plate.

Tsunamis

How underwater earthquakes trigger enormous and devastating waves

Water displacement

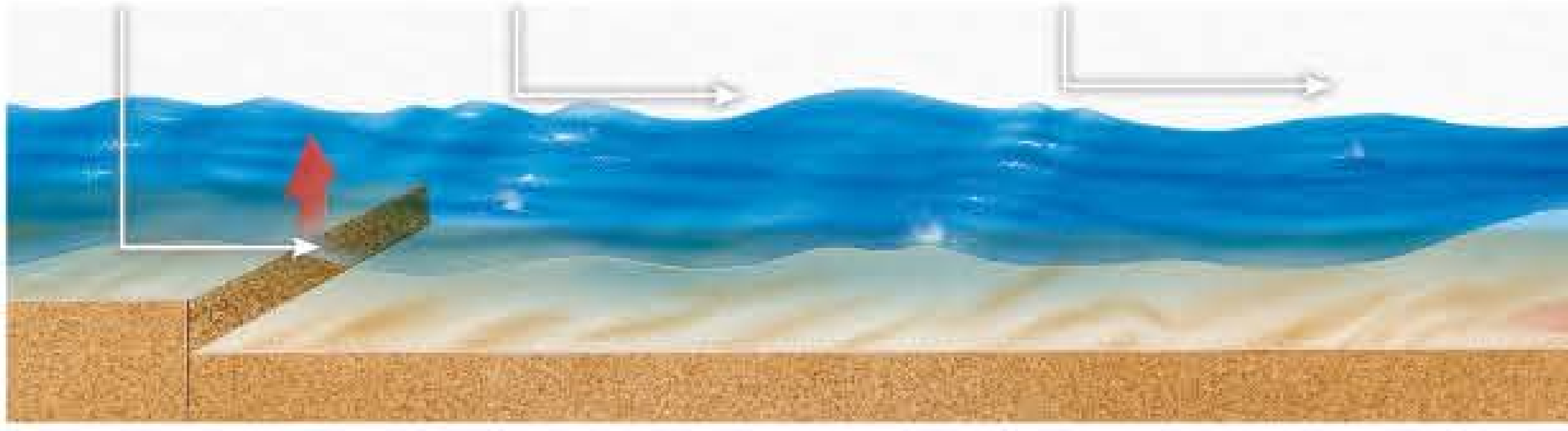
As two oceanic plates slip past each other and cause an earthquake, a huge amount of water above it is displaced.

Small beginnings

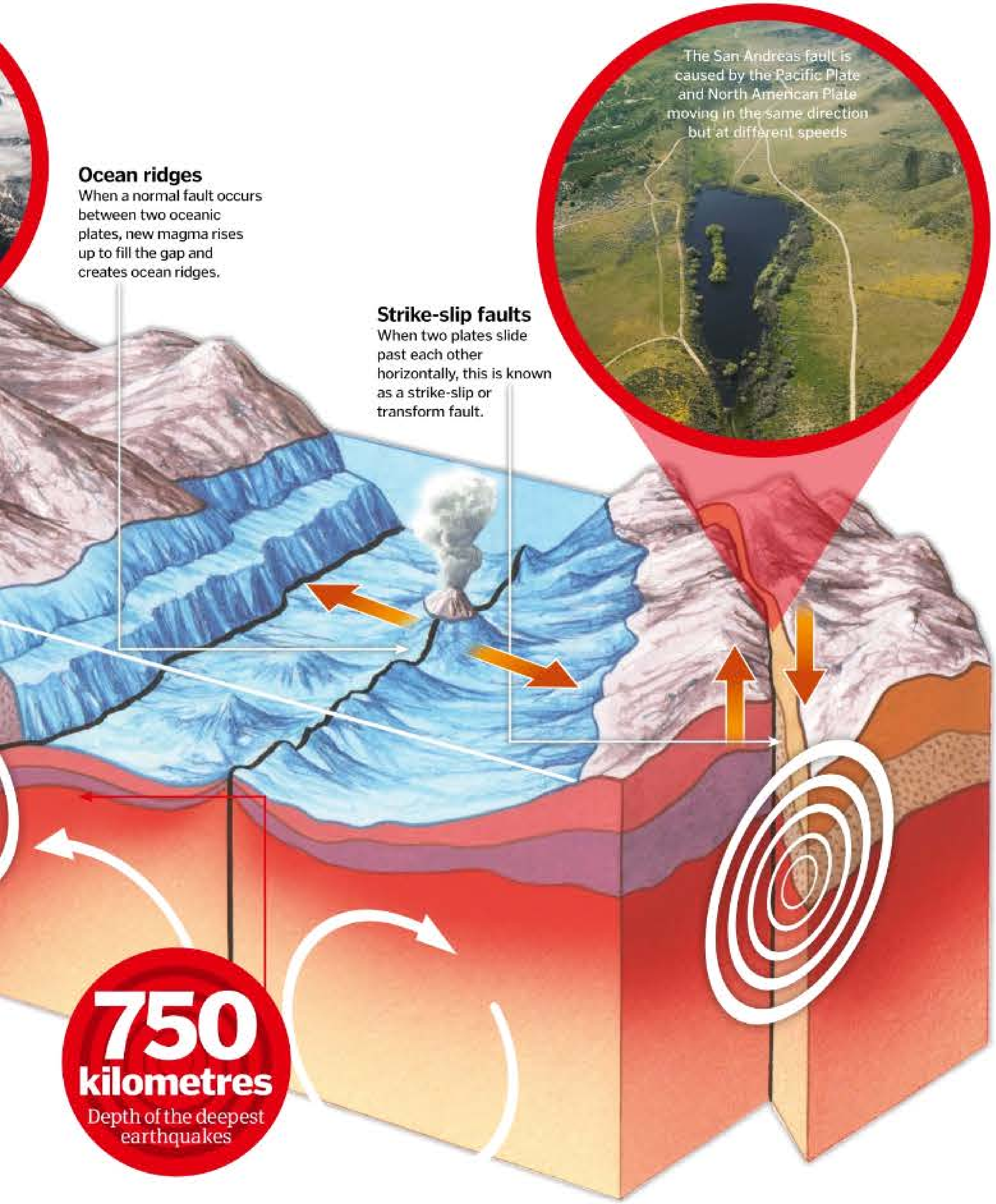
Small, rolling waves begin to spread outward from the earthquake's epicentre at speeds of up to 805km/h (500mph).

Tsunami in disguise

The tsunami's long wavelength and small wave height – usually less than 1m (3.3ft) – means that it blends in with regular ocean waves.



DID YOU KNOW? *Tsunamis and tidal waves are different things as the latter is caused by gravitational activity, not earthquakes*



The San Andreas fault is caused by the Pacific Plate and North American Plate moving in the same direction but at different speeds

Ocean ridges
When a normal fault occurs between two oceanic plates, new magma rises up to fill the gap and creates ocean ridges.

Strike-slip faults
When two plates slide past each other horizontally, this is known as a strike-slip or transform fault.

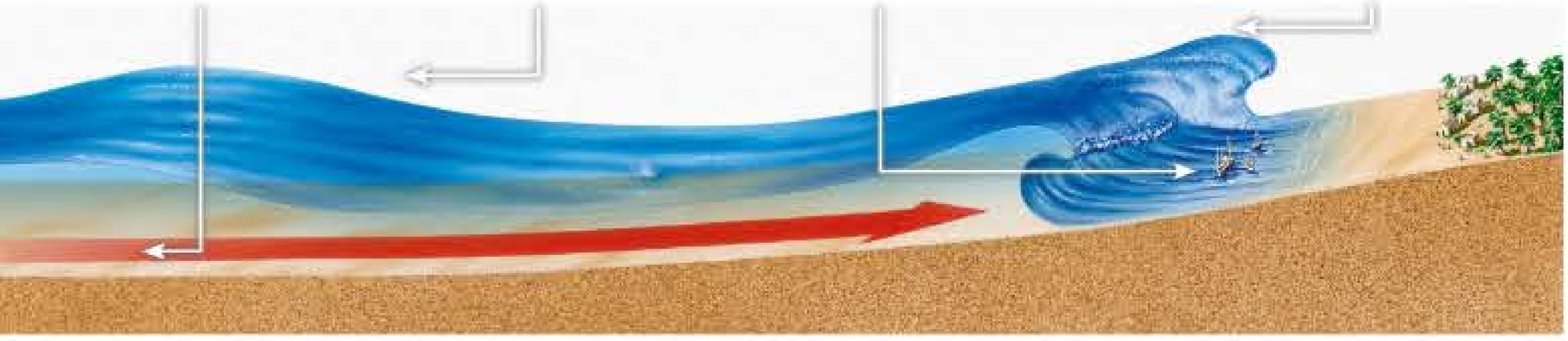
750 kilometres
Depth of the deepest earthquakes

Starting to slow
As they reach the shallower waters of the coast, the rising sea floor causes friction that slows the waves down.

Waves begin to grow
As they slow down, the wavelengths begin to shorten, causing the tsunami to grow to a height of approximately 30m (100ft).

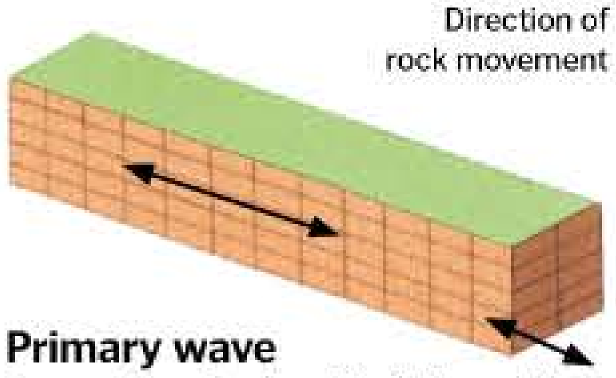
Early warning
A tsunami's trough, the low point beneath the wave's crest, often reaches shore first, producing a vacuum effect that sucks coastal water seaward.

The tsunami strikes
A few minutes later, the tsunami's crest will hit the shore followed by a series of more waves. This is known as a wave train.

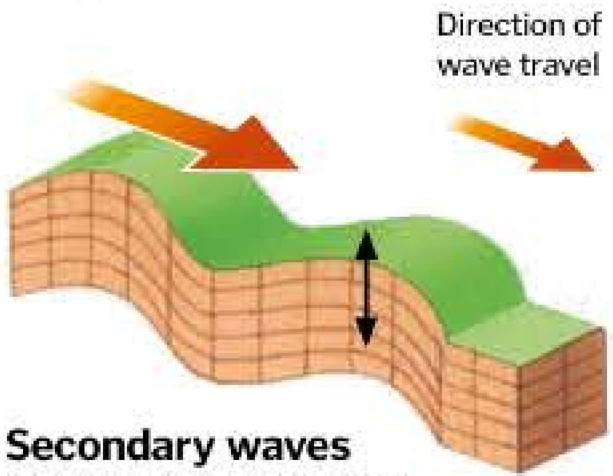


Earthquake waves

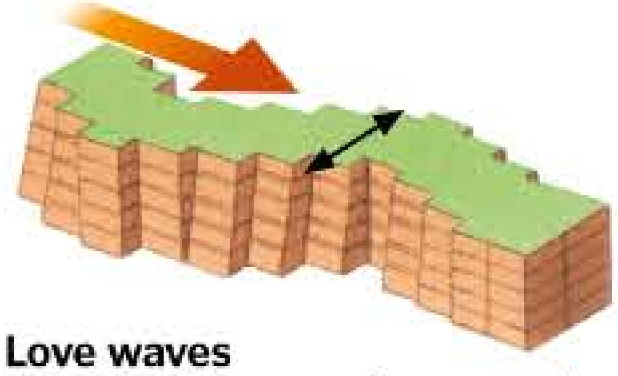
How seismic waves travel through the Earth's crust



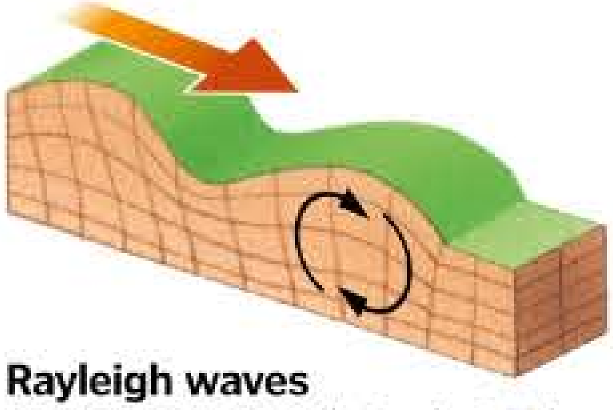
Primary wave
P waves travel back and forth through the Earth's crust, moving the ground in line with the wave. They are the fastest moving of the waves, travelling at about 6-11km/s (3.7-6.8mi/s) , and so typically arrive first with a sudden thud.



Secondary waves
S waves move up and down, perpendicular to the direction of the wave, causing a rolling motion in the Earth's crust. They are slower than P waves, travelling at about 3.4-7.2km/s (2.1-4.5mi/s), and can only move through solid material, not liquid.



Love waves
Unlike P and S waves, surface waves only move along the surface of the Earth and are much slower. Love waves, named after the British seismologist AEH Love, are the faster of the two types and shake the ground side to side, perpendicular to direction of the wave.



Rayleigh waves
Rayleigh waves, named after the British physicist Lord Rayleigh, are surface waves that cause the ground to shake in an elliptical motion. Surface waves arrive last during an earthquake but often cause the most damage to infrastructure due to the intense shaking they cause.

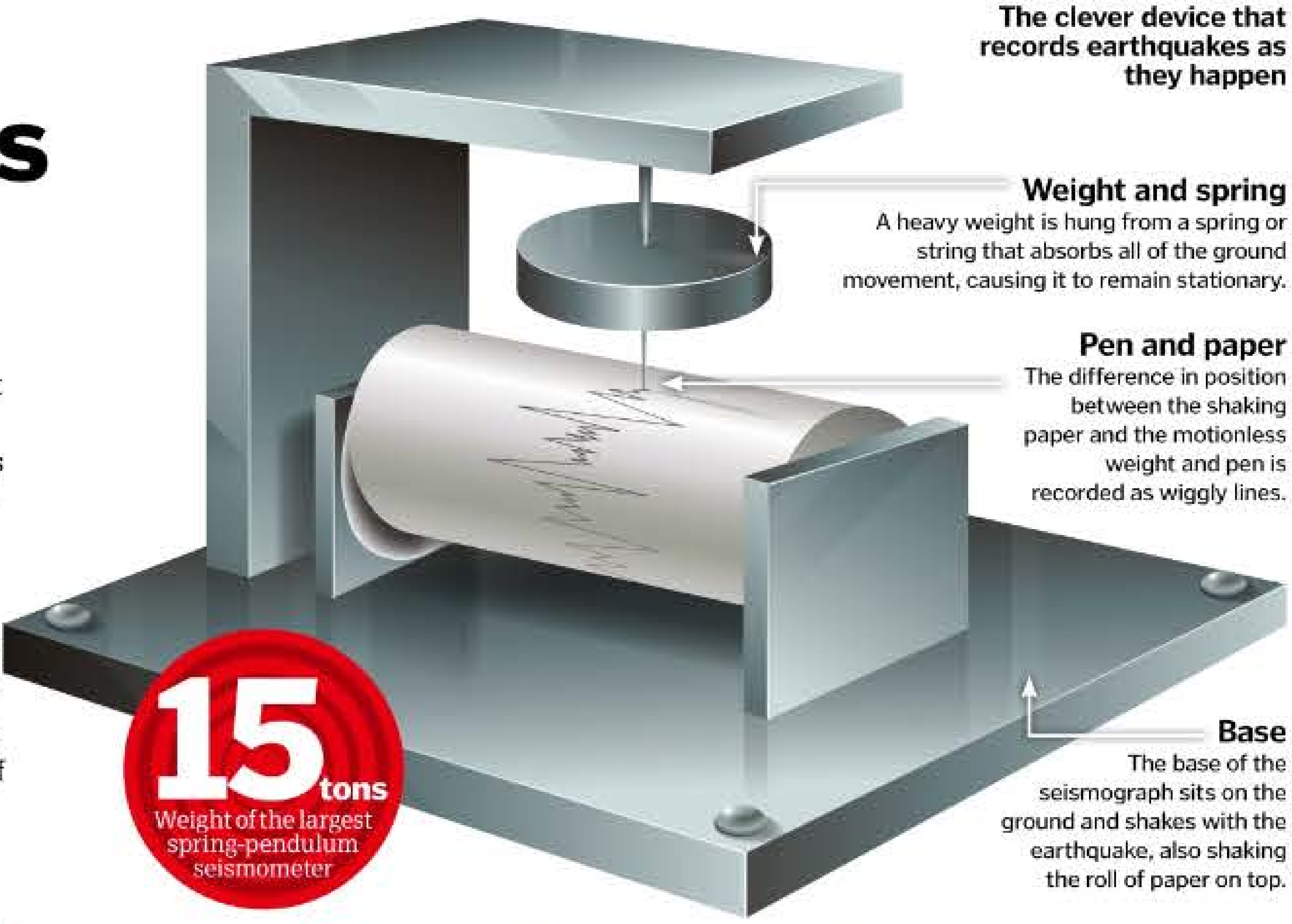
Monitoring earthquakes

Earthquake-recording methods of the past and present

Earthquakes are measured using an instrument called a seismograph, which produces a visual record of tremors in the Earth's crust. This shows the seismic waves of the earthquake as a wiggly line, allowing you to plot the different waves types. The small but fast P waves appear first, followed by the larger but slower S waves and surface waves. The amount of time between the arrival of the P and S waves shows how far away the earthquake was, allowing scientists to work out the exact location of the epicentre. The size of the waves also helps them determine the magnitude or size of the earthquake, which is measured using the Richter Scale.

How a seismograph works

The clever device that records earthquakes as they happen

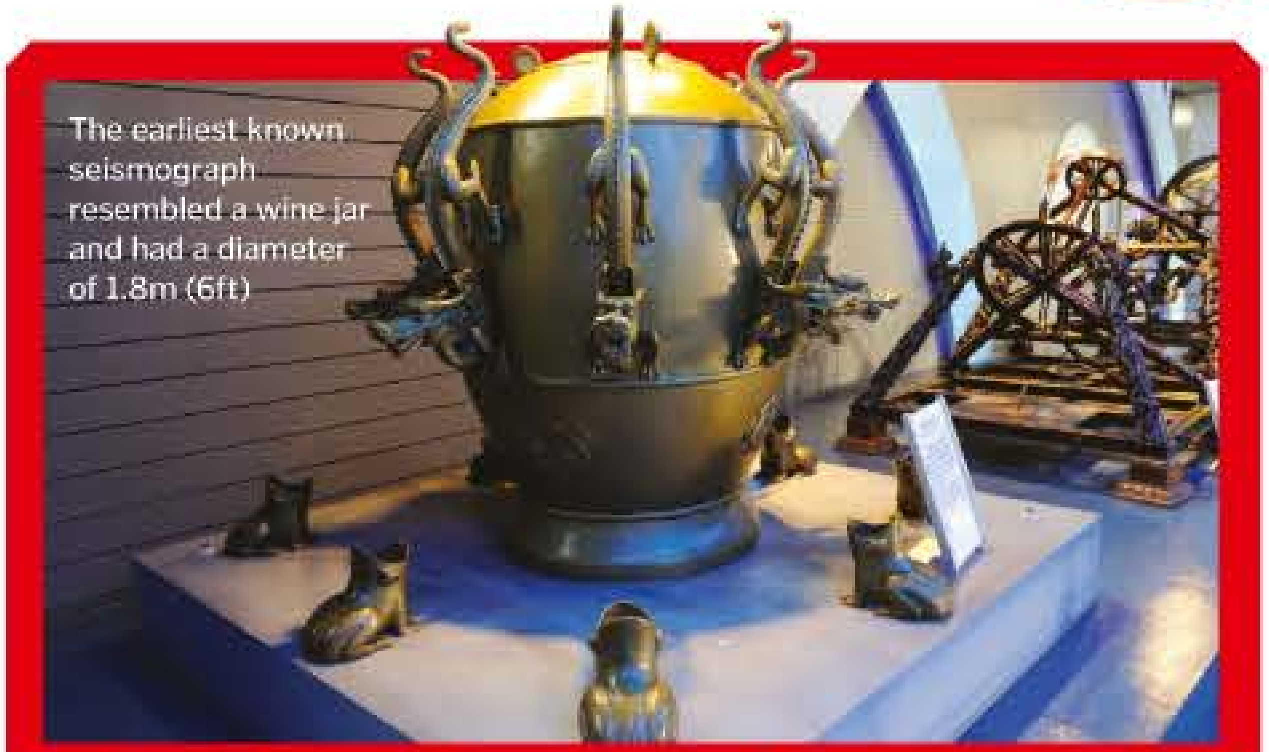


Weight and spring
A heavy weight is hung from a spring or string that absorbs all of the ground movement, causing it to remain stationary.

Pen and paper
The difference in position between the shaking paper and the motionless weight and pen is recorded as wiggly lines.

Base
The base of the seismograph sits on the ground and shakes with the earthquake, also shaking the roll of paper on top.

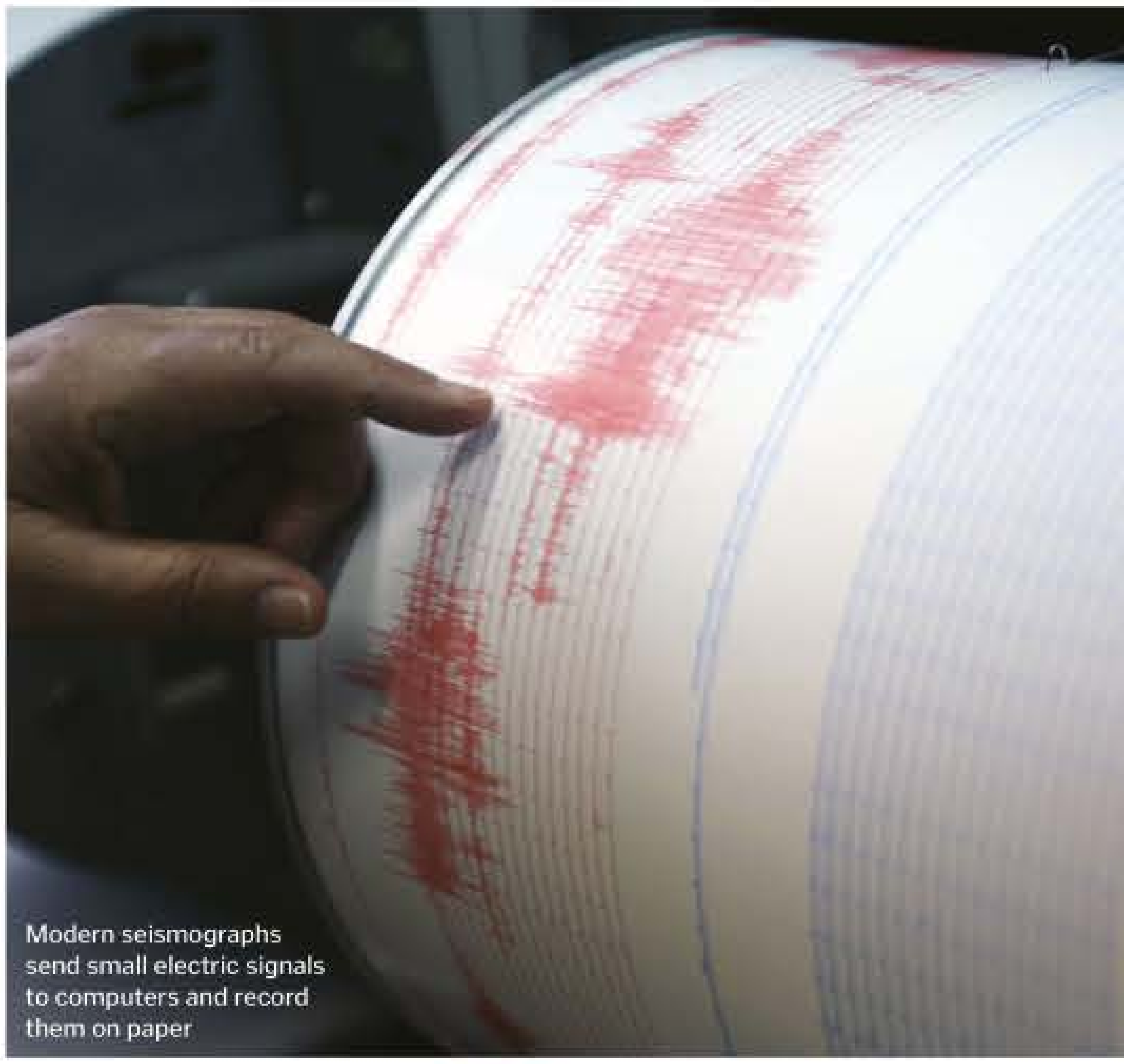
15 tons
Weight of the largest spring-pendulum seismometer



The earliest known seismograph resembled a wine jar and had a diameter of 1.8m (6ft)

The first seismograph

The earliest known seismoscope was invented by Chinese philosopher Chang Hêng in 132. It didn't actually record ground movements, but simply indicated that an earthquake had hit. The cylindrical vessel had eight dragon heads around the top, facing the eight principal directions of the compass, each with an open-mouthed toad underneath it. Inside the mouth of each dragon was a ball that would drop into the mouth of the toad below when an earthquake occurred. The direction of the shaking could be determined by which dragon released its ball. It is not known what was inside the vessel, but it is thought that some kind of pendulum was used to sense the earthquake and activate the ball in the dragon's mouth. The instrument reportedly detected a 650-kilometre (373-mile)-distant earthquake which was not felt by people at the location of the seismoscope.



Modern seismographs send small electric signals to computers and record them on paper

The Richter Scale

Measuring the magnitude of earthquakes using US seismologist Charles F Richter's system

0-2.9
There are more than 1 million micro earthquakes a year but they are not felt by people.

3.0-3.9
Minor earthquakes are felt by many people but cause no damage – there are as many as 100,000 of these a year.

4.0-4.9
Felt by all, light earthquakes occur up to 15,000 times a year and cause minor breakages.

5.0-5.9
A moderate earthquake causes some damage to weak structures. There are around 1,000 of them a year.

DID YOU KNOW? *The earliest recorded evidence of an earthquake has been traced back to 1831 BCE in China's Shandong province*

Laser beams are used to detect small movements of the ground in Parkfield, California

With a little bit of warning, people can hide under tables and desks to protect them from falling debris in an earthquake

Predicting earthquakes

Modern methods that could help us plot future seismic activity

Currently, earthquakes cannot be predicted far enough in advance to give people much notice, but there are some early warning systems in place to give people a few seconds or minutes to prepare before the serious shaking starts. When seismometers detect the initial P waves, which don't usually cause much damage, they can estimate the epicentre and magnitude of the earthquake and alert the local population before the more destructive S waves arrive. Depending on their distance from the epicentre, people should then have just enough time to take cover, stop transport and shut down industrial systems in order to reduce the number of casualties.

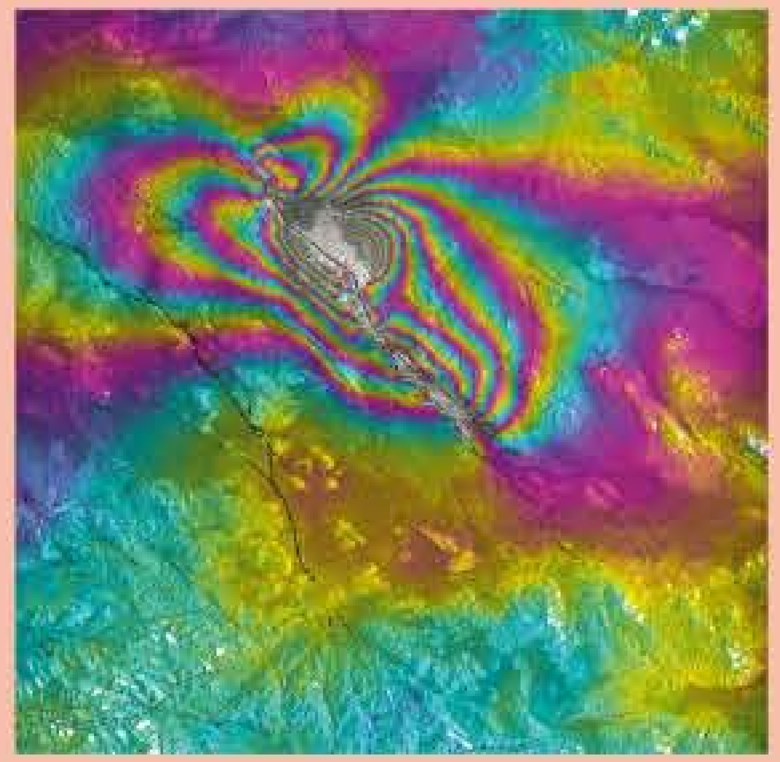
Scientists are also enlisting the help of the general public to help them develop early warning systems. The Quake-Catcher Network (QCN) is a worldwide initiative supplying people with low-cost motion sensors that they can fasten to the floor in their home or workplace. These sensors are then connected to their computer and send real-time data about seismic activity to the QCN's servers, with the hope that earthquake warnings can be issued when strong motions are detected in any of these.

To be able to predict earthquake further in advance, a characteristic pattern or change that precedes each earthquake needs to be identified. One suggestion is that increased levels of radon gas escape from the Earth's crust before a quake, however this can also occur without being followed by seismic activity, so does not provide conclusive evidence of a earthquake.

Scientists are even trying to determine whether animals can predict earthquakes better than we can, but no widespread unusual behaviour has been linked to earthquakes. Other potential earthquake-predicting methods are being tested in Parkfield, California along the San Andreas fault. Among other things, scientists are using lasers to detect the movement of the Earth's crust, sensors to monitor groundwater levels in wells, and a magnetometer to measure changes in the Earth's magnetic field, all with the hope that this will allow them to predict the next big quake.

Radar mapping

One of the more recent developments in earthquake monitoring is interferometric synthetic aperture radar (InSAR). Satellites, or specially adapted planes, send and receive radar waves to gather information about the features of the Earth. The reflected radar signal of a fault line is recorded multiple times to produce radar images, which are then combined to produce a colourful interferogram (below). Each colour shows the amount of ground displacement that has occurred between the capturing of each image, mapping the slow warping of the ground surface that leads to earthquakes. This technique is sensitive enough to detect even tiny ground movements, allowing scientists to monitor fault lines in more detail and detect points where immense pressure is building up. It is hoped that this data will eventually enable scientists to tell when this pressure has reached a hazardous level, leading to more reliable earthquake predictions that give the public days or even weeks to prepare.



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6.0-6.9

Over 100 strong earthquakes happen each year, causing moderate damage in populated areas.

7.0-7.9

A loss of life and serious damage over large areas are the result of major earthquakes that happen around ten times a year.

8.0 & higher

There are fewer than three earthquakes classed as 'great' each year, but they cause severe destruction and loss of life over large areas.

How cenotes form

Dip your toe into a world where geology and ancient history go hand in hand

Found on Mexico's Yucatán peninsula, a cenote (pronounced 'say-no-tay') is effectively a really pretty sinkhole. These colossal underground caverns are filled with deep, crystal-clear water and are used as both swimming and diving spots for tourists and scuba enthusiasts, not to mention being sites of incredible archaeological and cultural significance for the Yucatán's locals.

The Yucatán peninsula is formed of limestone and was once a coral reef, exposed just above sea level during the last ice age. The peninsula doesn't have many rivers or steams above ground, but below the surface flow the three longest underground water systems in the world. These essential waters have helped civilisation thrive on the Yucatán for thousands of years.

Fractures in the limestone bedrock form the beginnings of a cenote. Rain and groundwater, which can be slightly acidic, filter through these cracks. This acidic liquid then slowly dissolves the soft limestone, meaning the cracks gradually get larger and larger. Due to the low-lying land, over millennia more water filters through the rock and a cave eventually forms. This cave is then filled up with the subterranean water that flows beneath the ground.

Over time, the water wears the limestone away to create great, cavernous chambers. The ceilings of these chambers are the weakest part, and when they eventually cave in the structure is then known as a cenote. From above, sunlight streams in and tree roots crack through the rock, reaching downwards for the moisture below.

There are over 6,000 cenotes in the Yucatán peninsula, although only 2,400 are studied and registered. With their giant, cathedral-like domes filled with dizzyingly deep and clear water, it's quite easy to see why ancient civilisations considered these rock formations to be entrances to other worlds and feared what lay within.

DID YOU KNOW? *A human skeleton found in one cenote near the Mexican resort of Tulum was found to be 12,000 years old*

"The water wears the limestone away to create great cavernous chambers"

The world's longest underground river

Beneath the surface, Mexico's Yucatán peninsula is a labyrinth of limestone caves and underground waterways. The title for 'longest underground river' was previously claimed by the Puerto Princesa Subterranean River in the Philippines, which runs for 8.2 kilometres through limestone caves before joining the South China Sea.

Now, thanks to four years of exploration by British and German divers, the Sac Actun (meaning 'white cave') river system has been discovered to run for 153 kilometres through the Yucatán's limestone maze, earning it the title of the world's longest running underground river.

The discovery occurred when the divers found a link between the region's two longest cave systems, the Sac Actun and the Nohoch Nah Chich (meaning 'giant birdcage'). The entire network, which is now collectively known as Sac Actun (including the dry caves without the flow of the river), has a total surveyed length of 319 kilometres, making it also the second longest cave system in the world, behind the 644-kilometre Mammoth Cave system in Kentucky.

A cave diver in Chac Mool Cenote, Playa del Carmen, in the Yucatán Peninsula, Mexico

© Alamy; WIKI

Mountain formation

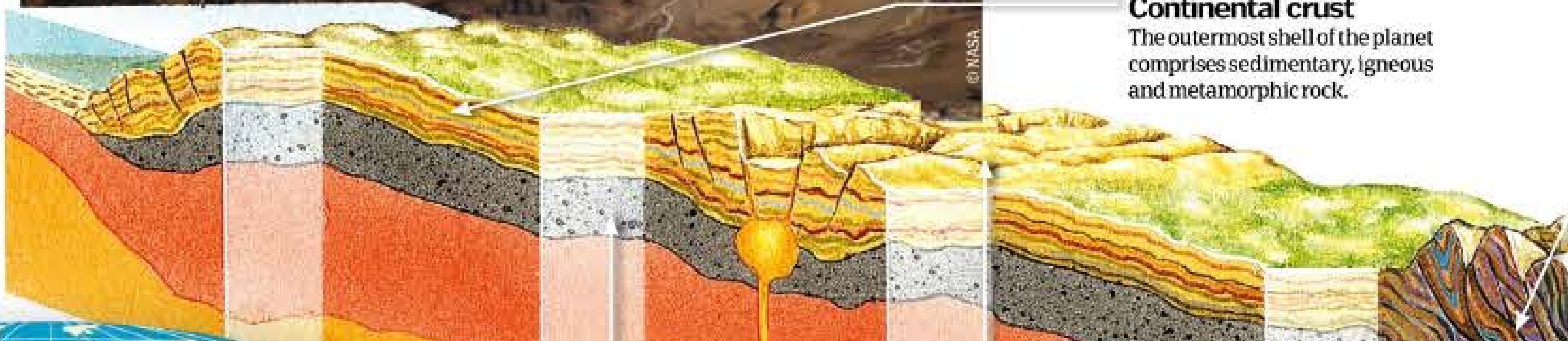
How many ways can you make a mountain?

Mountains are massive landforms rising high above the Earth's surface, caused by one or more geological processes: plate tectonics, volcanic activity and/or erosion. Generally they fall into one of five categories – fold, fault-block, dome, volcanic and plateau – although there can be some overlap.

Mountains comprise about 25 per cent of our land mass, with Asia having more than 60 per cent of them. They are home to 12 per cent of the Earth's population, and they don't just provide beauty and recreation; more than half of the people

The Himalayas are home to the world's highest peaks

© NASA



Continental crust
The outermost shell of the planet comprises sedimentary, igneous and metamorphic rock.

Lithosphere
This rocky, rigid layer includes the oceanic and continental crusts and part of the mantle. Tectonic plates reside in this layer.

Fault-block mountains
Fractures in the tectonic plates create large blocks of rock that slide against each other. Uplifted blocks form mountains.

Asthenosphere
This semiplastic region in the upper mantle comprises molten rock and it's the layer upon which tectonic plates slide around.

ON THE MAP

10 major mountain ranges

1. Ural Mountains
TYPE: Fold mountain range in Russia and Kazakhstan

2. Altai Mountains
TYPE: Fault-block mountain range in Central Asia

3. Tian Shan
TYPE: Fault-block mountain range in Central Asia

4. Sumatra-Java range
TYPE: Discontinuous mountain range system containing active volcanoes, ranging the length of Sumatra (the Barisan Mountains) and Java

5. Serra do Mar
TYPE: Discontinuous mountain range system on east coast of Brazil, fault-block formation

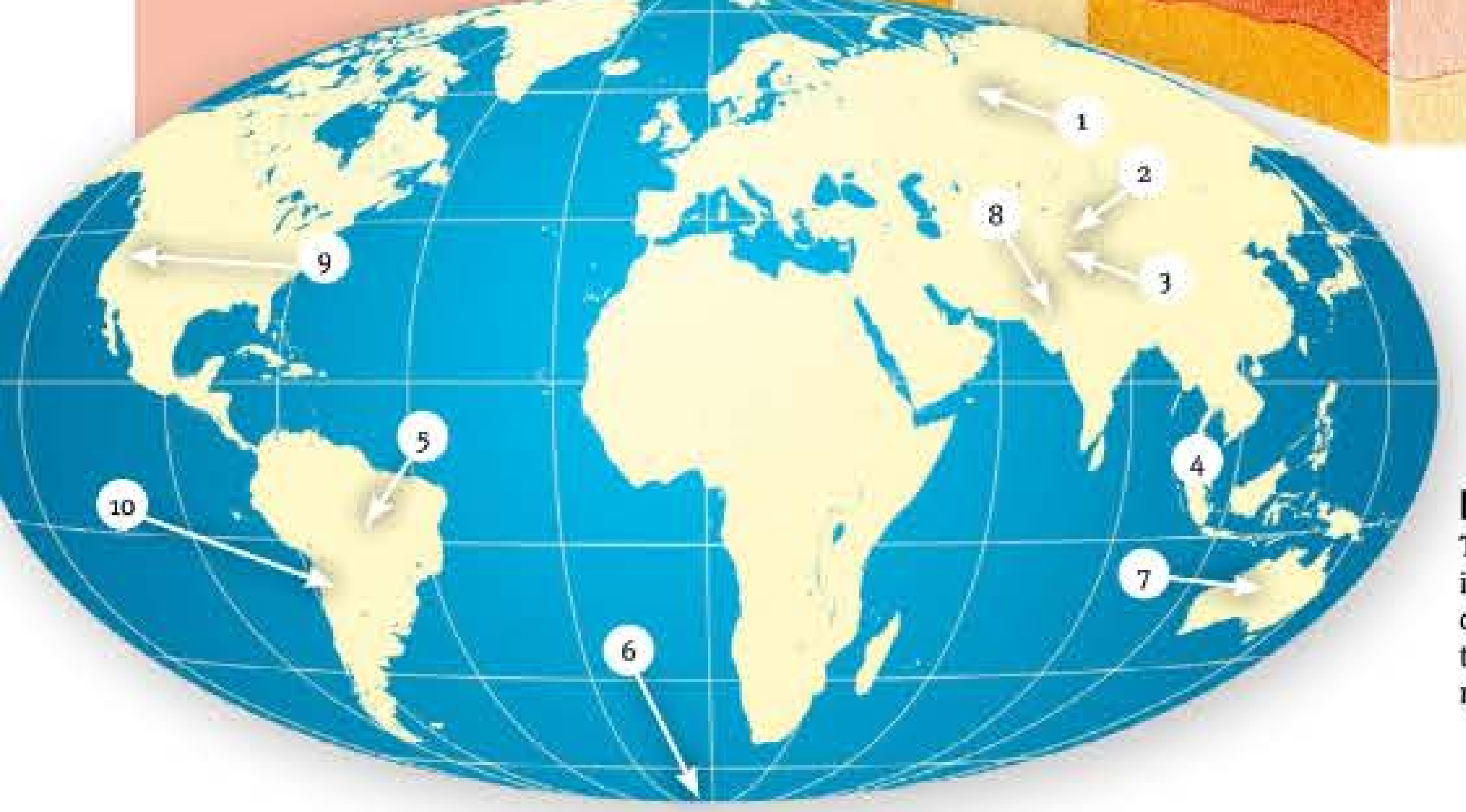
6. Transantarctic Mountains
TYPE: Fault-block mountain chain that serves as a division between East and West Antarctica

7. Eastern Highlands
TYPE: Discontinuous fold mountain range system dominating eastern Australia

8. Himalayas
TYPE: Fold mountain range system in Asia between India and the Tibetan Plateau

9. Rocky Mountains
TYPE: Fold mountain range in western North America

10. Andes
TYPE: Fold mountain range in South America



DID YOU KNOW? *There is no universal definition of a mountain. For some it means a peak over 300m (984ft) above sea level*

on Earth rely on the fresh water that flows down from the mountains to feed streams and rivers. Mountains are also incredibly biodiverse, with unique layers of ecosystems depending on their elevation and climate.

One of the most amazing things about mountains is that although they look solid and immovable to us, they're always changing and sometimes even growing. Mountains rising from activity associated with plate tectonics – fold and fault-block – form slowly over millions of years. The plates and rocks that initially interacted to form the mountains continue to move up to 2cm (0.8in) each year, meaning that the mountains grow. The Himalayas grow about 1cm (0.4in) per year.

The volcanic activity that builds mountains can wax and wane over time. Mount Fuji, the tallest mountain in Japan, has erupted 16 times since 781AD. Mount Pinatubo in the Philippines erupted in the early-Nineties without any prior recorded eruptions, producing the second largest volcanic eruption of the 20th century. Inactive volcanic mountains – and all other types of mountains, for that matter – are also subject to erosion, earthquakes and other activity that can dramatically alter their appearances as well as the landscape around us. There are even classifications for the different types of mountain peaks that have been affected by glacial periods in Earth's history. The bare, near-vertical mountaintop of the Matterhorn in the Alps, for example, is known as a pyramidal peak, or horn.

Types of mountain

Fold

This most common type of mountain is formed when two tectonic plates smash into each other. The edges buckle and crumble, giving rise to long mountain chains.

Examples: Mount Everest, Aconcagua

Volcanic

These mountains are created by the buildup of lava, rock, ash and other volcanic matter during a magma eruption.

Examples: Mount Fuji, Mount Kilimanjaro

© Daniel Case

Plateau

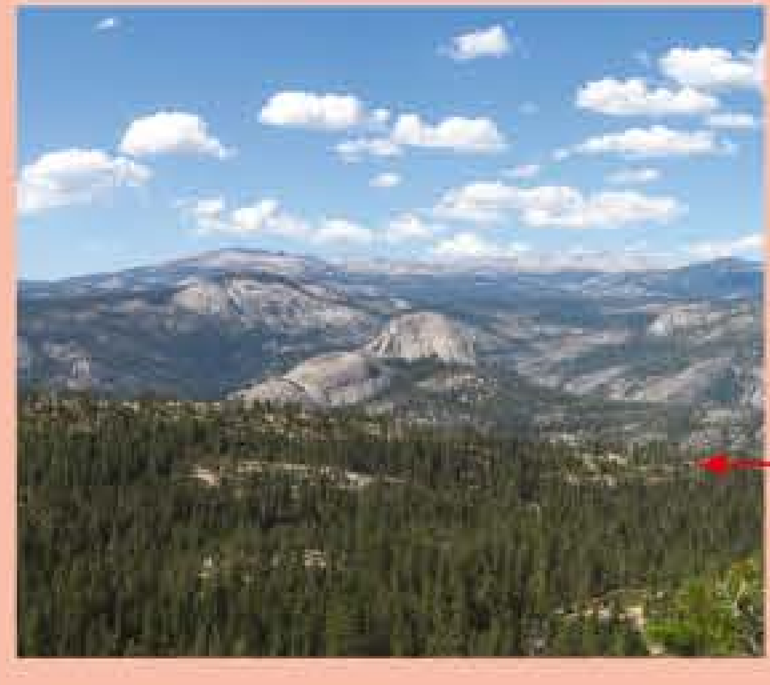
Plateau mountains are revealed through erosion of uplifted plateaux. This is known as dissection.

Examples: Catskill Mountains, Blue Mountains

Dome

These types of mountain also form from magma. Unlike with volcanoes, however, there is no eruption; the magma simply pushes up sedimentary layers of the Earth's crust and forms a round dome-shaped mountain.

Examples: Navajo Mountain, Ozark Dome

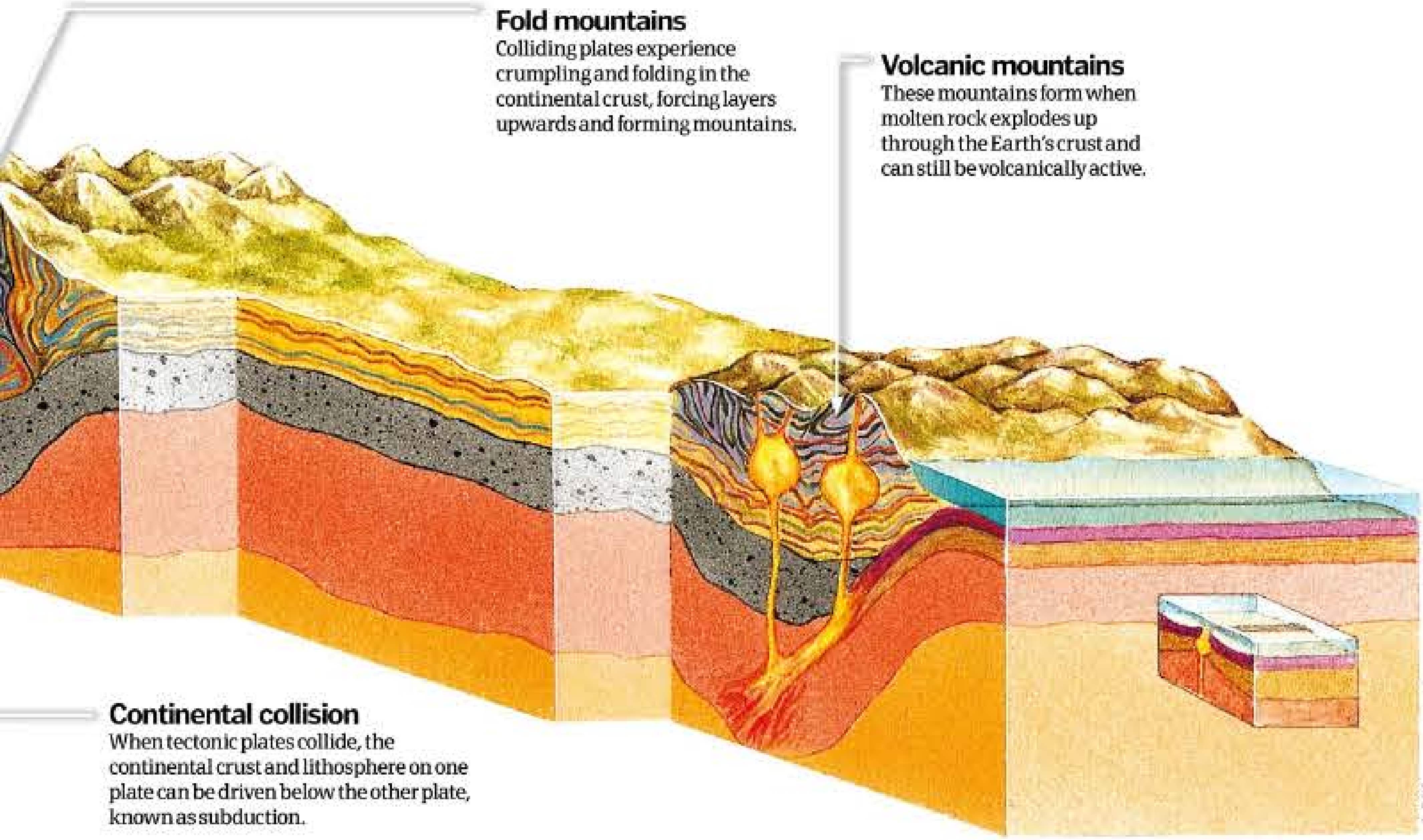


Fault-block

Fault-block mountains form when cracked layers of crust slide against each other along faults in the Earth's crust. They can be lifted, with two steep sides; or lifted, with one gently sloping side and one steep side. **Examples:** Sierra Nevada, Urals

© NASA

Mountains made from below



Fold mountains

Colliding plates experience crumpling and folding in the continental crust, forcing layers upwards and forming mountains.

Volcanic mountains

These mountains form when molten rock explodes up through the Earth's crust and can still be volcanically active.

Continental collision

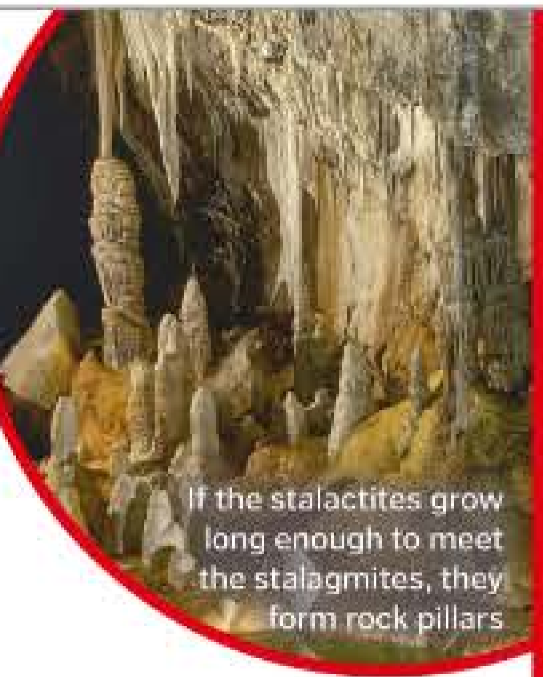
When tectonic plates collide, the continental crust and lithosphere on one plate can be driven below the other plate, known as subduction.

© DK Images

Mountains are home to 12 per cent of the world's population

Stalagmite and stalactite formation

Discover the development of these curious subterranean spikes



If the stalactites grow long enough to meet the stalagmites, they form rock pillars

Struggling to tell the difference between these two formations? When you see the letter 'c' in stalactites, think 'ceiling', as they hang from the roofs of caves. And when you see the 'g' in stalagmites, think 'ground', as they rise from the floor like inverted icicles. Both structures are known as speleothems, and are formed over thousands of years, as water trickles through the cave and minerals are deposited layer upon layer.

Stalactites

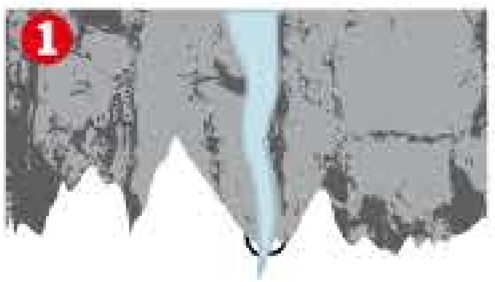
Steady drops of water build these structures downwards

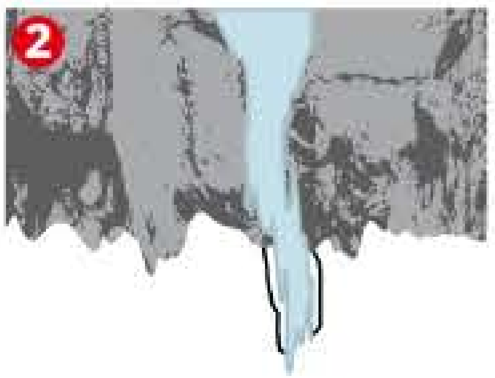
1 Water drops
Water slowly filters through the many cracks and pores in the rock until it hangs as a drip on the cave ceiling.

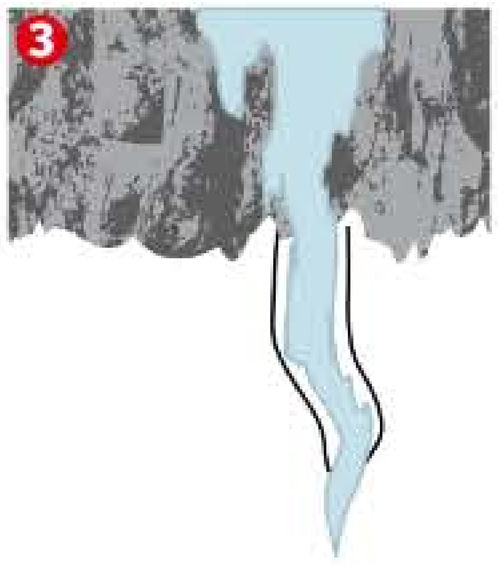
2 Gradual build-up
Calcium carbonate is carried in the water – when it meets the air, it solidifies to form a tiny solid ring around the droplet.

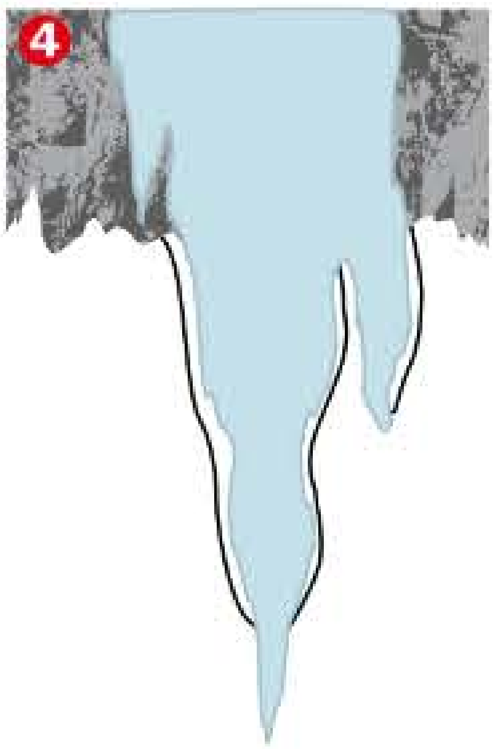
3 Layer upon layer
Straw stalactites form, where a long and thin deposit is built up with a hollow middle that water drips through.

4 Sturdier speleothems
As more and more mineral deposits build up on the stalactite, it gets longer, wider and more robust.



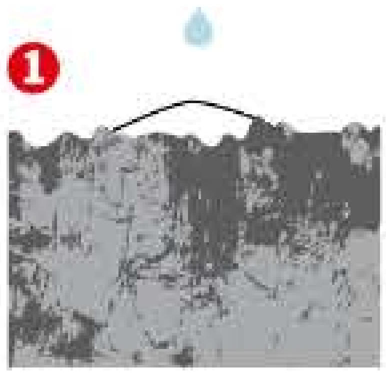


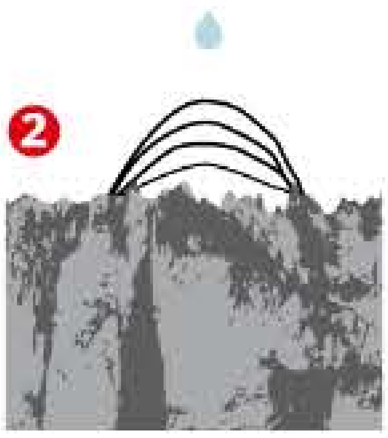


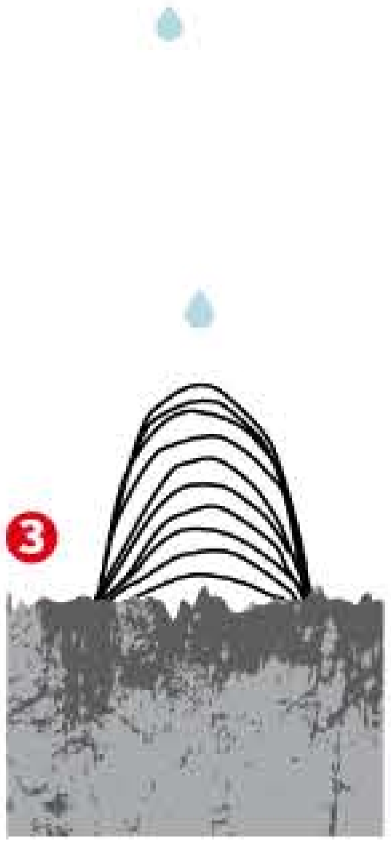


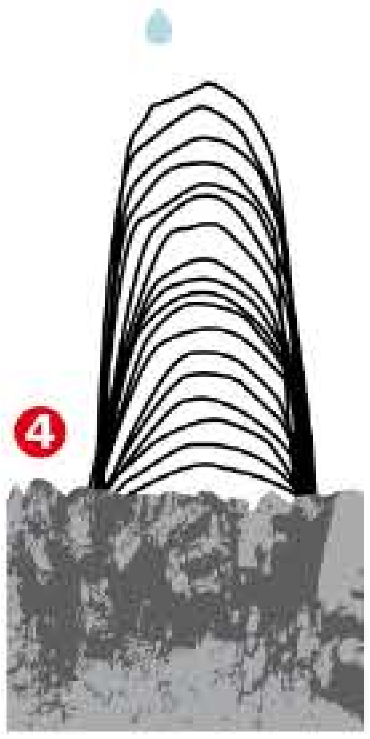
Stalagmites

These formations slowly rise upwards from the cave floor









1 Drops from above
As the same droplets that form stalactites hit the floor, calcium carbonate solidifies to form the base of a stalagmite.

2 Rounded shapes
The shape of a stalagmite is a rounded dome. As more drops hit the same patch of floor, the shape begins to build.

3 Slower 'growth'
The floor formations don't build up as quickly as stalactites, but the two structures can eventually meet to form a pillar.

4 Weather record
Analysing a stalagmite can reveal its age. Layers will be compact during wetter years and spaced apart for drier years.

What is soil made of?

The ingredients that form one of Earth's most important natural resources

In its simplest form, soil is a gritty mixture of ground-up minerals and decaying organic matter, such as leaf litter from the forest canopy. These raw ingredients are then mixed and churned together by the bugs and worms that live within.

The broken-up rocks that make up soil can come from the bedrock that lies deep below, or from other sources, where rocks, rubble and more soil is transported by forces such as rivers or glaciers.

There are six major types of soil, each with different mineral quantities and qualities. Clay soils are dense but high in nutrients, sandy soils are light, dry and relatively acidic, while silt soils are very fertile and hold plenty of moisture. Loam soils contain a balance of clay, sandy and silt soil types, while peat soil types are full of organic matter and chalky soils contain calcium carbonate and are therefore very alkaline.

Many different types of soil will build up in layers in any given spot, making what is known as soil horizons. These layers usually consist of organic matter in various stages of decay, depending on the locality.

Soil appears darker when there is more organic matter, or 'humus', present

© Thinkstock

Located in Honshu, Japan, Mount Zao's crater lake is sometimes called Five Colour Pond as it changes hues according to the weather

How do crater lakes form?

Dive in to the geology behind these bodies of water with an explosive past

When you look out across a mountain lake it can be easy to think it was always so serene, but this couldn't be further from the truth. From the shifting of Earth's tectonic plates to glaciers gouging out the land, the majority of these tranquil sites are the result of epic geological events.

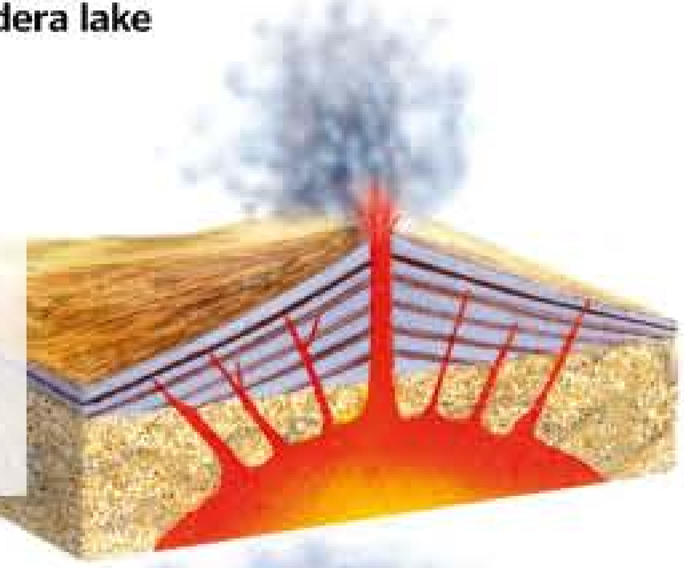
Crater lakes have the most epic beginnings of all. While maar lakes are also the result of volcanism, forming in fissures left behind by ejected magma, they are generally shallow; Devil Mountain Maar in Alaska is the deepest at just 200 metres (660 feet). Maars aren't a patch on their bigger cousins.

Crater lakes have very violent origins. During a mega-eruption, or series of eruptions, the terrain becomes superhot and highly unstable. In some cases the volcanic activity is so intense that once all the ash and smoke clears, the cone is revealed to have vanished altogether, having collapsed in on itself. This leaves a massive depression on the top of the volcano known as a caldera.

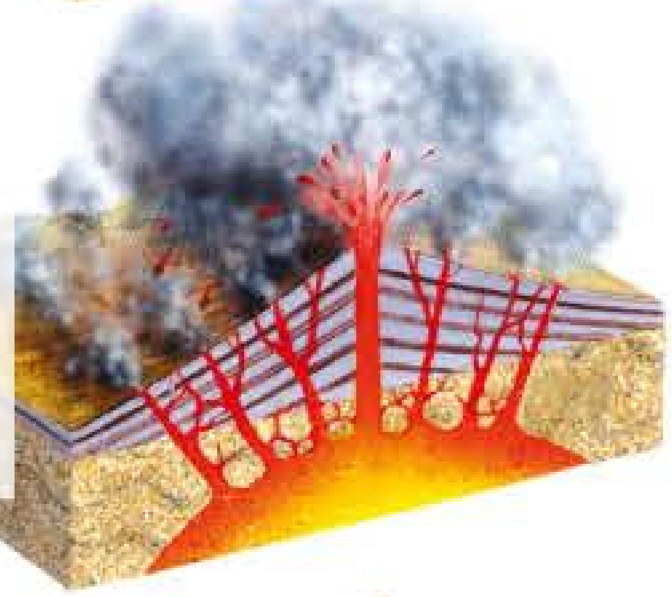
In the period of dormancy that follows, rain and snow gather in this basin, sometimes over several centuries, to create a deep body of water; Crater Lake in Oregon is the deepest of any lake in the USA, plunging to 592 metres (1,943 feet). Over time a caldera lake will reach a perpetual level maintained by a balance of regional precipitation and annual evaporation/seepage.

Crater lake in the making

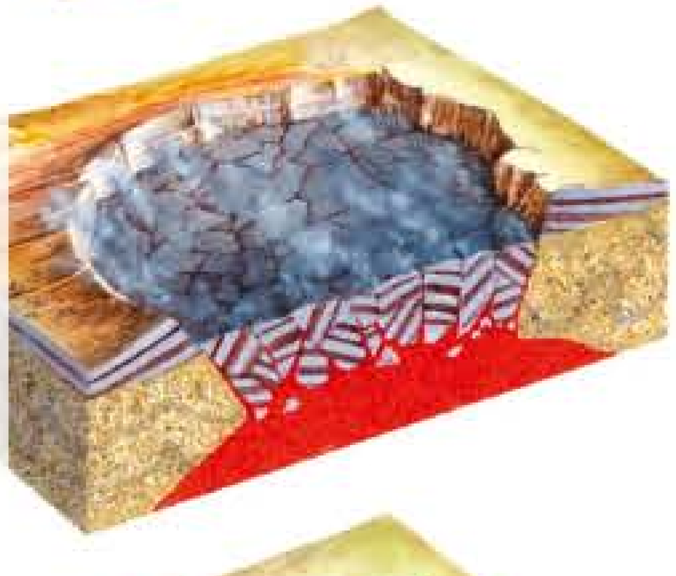
We pick out four key stages in the development of a caldera lake



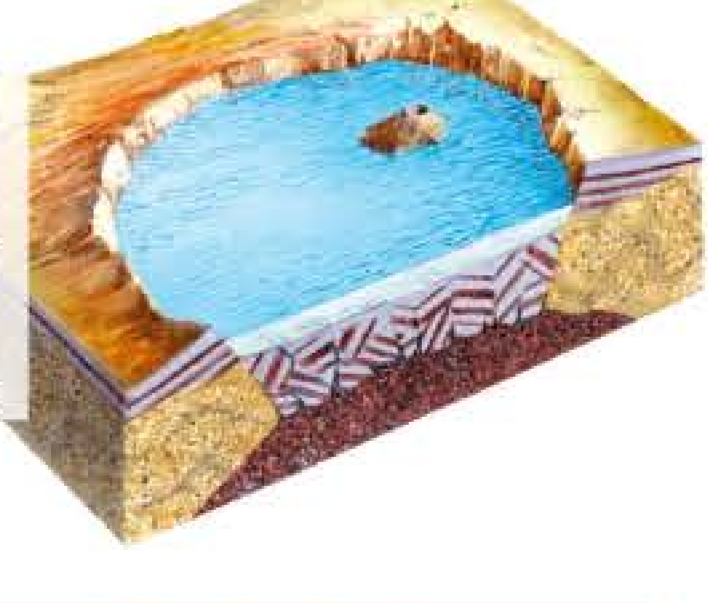
1. Volcano
All volcanoes feature a crater to some extent at their peak, but lakes rarely get the chance to form because of geothermal activity.



2. Mega-eruption
If a volcano has lain dormant for a long time, or if there is dramatic tectonic activity, a much bigger eruption than normal might occur.

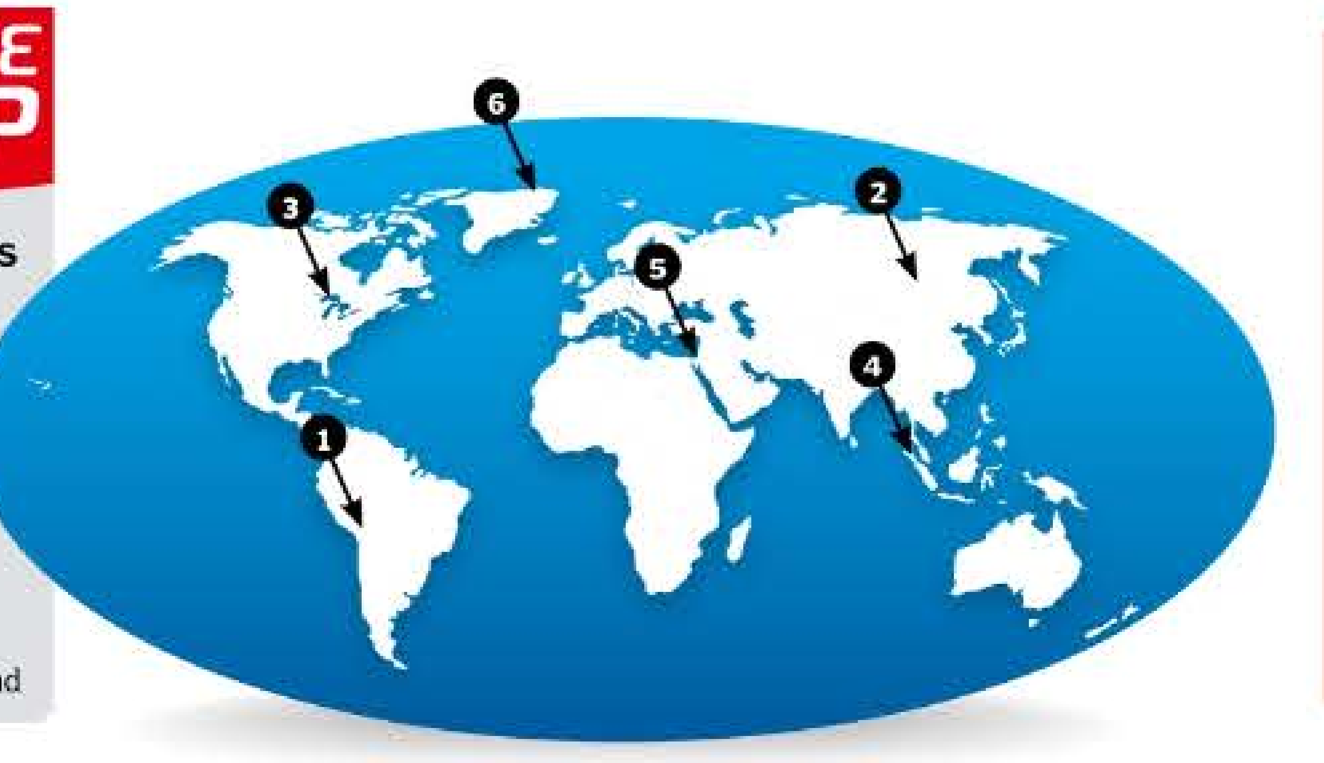


3. Collapse
Such a climactic event at the very least expands the size of the crater, however in more extreme cases the volcano's entire cone collapses inwards to leave a caldera.



4. Lake
Over centuries, the magma chamber below the caldera turns solid. In the cooler basin, rain and snow have an opportunity to build up and form a lake.

ON THE MAP



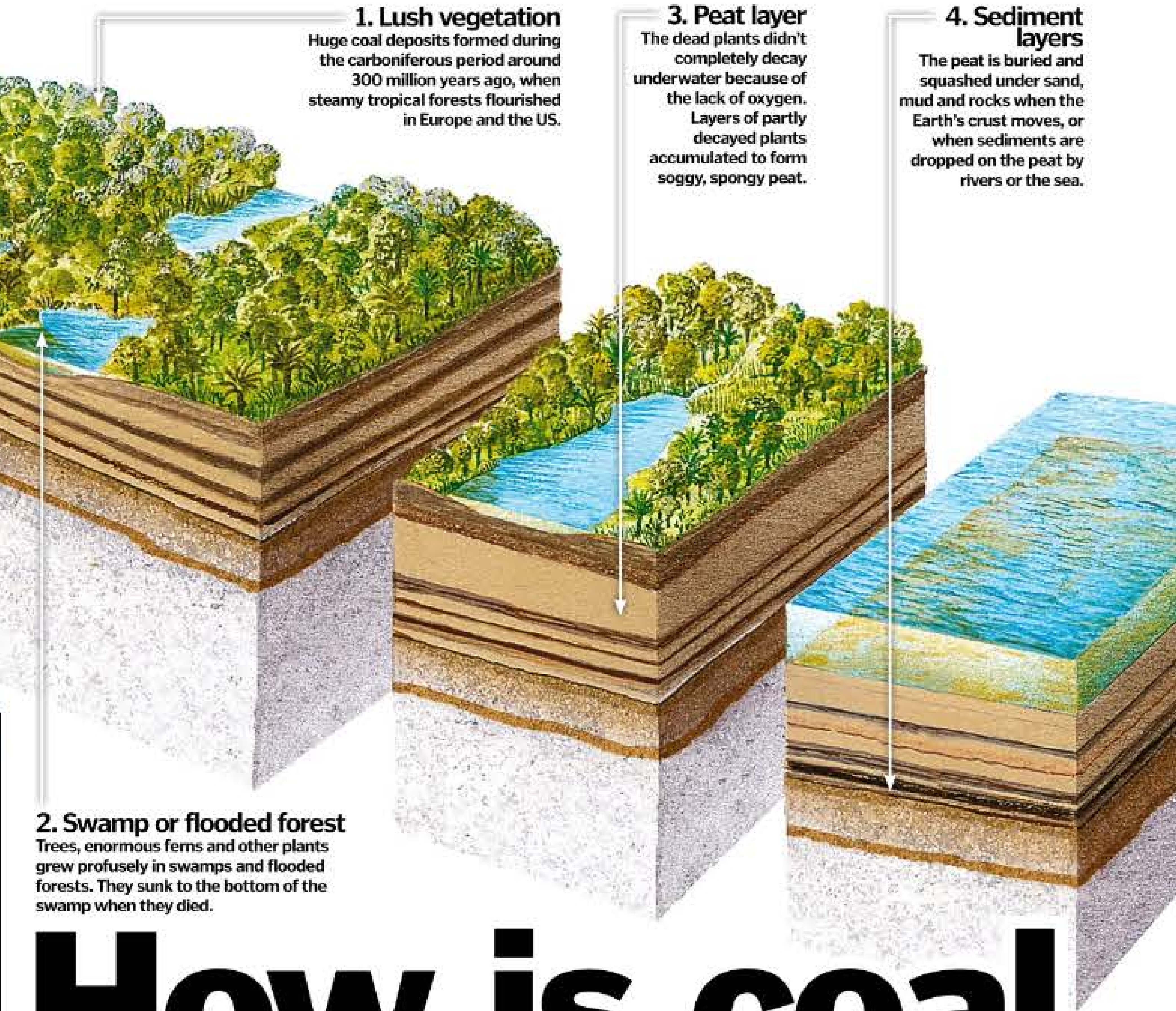
Record-breaking lakes

1. Highest navigable lake: Titicaca, Peru/Bolivia
2. Deepest: Baikal, Russia
3. Biggest lake group: Great Lakes, USA
4. Largest crater lake: Toba, Indonesia
5. Lowest: Dead Sea, Israel/Jordan
6. Most northerly: Kaffeklubben Sø, Greenland

Some like it hot...

Volcanic activity can continue to simmer under the crater, which affects the chemistry of the lake. A lack of productivity often means the water is very clear, hence why jewel-like greens and blues are common. This doesn't mean crater lakes are barren though. Some are a lot more hospitable than others, supporting insects, fish, right through to apex predators. But even ones spewing out deadly gases and minerals can still support ecosystems. For instance, the water of hyper-alkaline (pH 11) Laguna Diamante in the Andes contains arsenic and is five times saltier than seawater, but a research team in 2010 found 'mats of microbes' living on the lake bed, which served as food for a colony of flamingos.

© SPL


1. Lush vegetation
Huge coal deposits formed during the carboniferous period around 300 million years ago, when steamy tropical forests flourished in Europe and the US.
3. Peat layer
The dead plants didn't completely decay underwater because of the lack of oxygen. Layers of partly decayed plants accumulated to form soggy, spongy peat.
4. Sediment layers
The peat is buried and squashed under sand, mud and rocks when the Earth's crust moves, or when sediments are dropped on the peat by rivers or the sea.
2. Swamp or flooded forest
Trees, enormous ferns and other plants grew profusely in swamps and flooded forests. They sunk to the bottom of the swamp when they died.

How is coal formed?

Discover how your laptop is powered by plants that died before the dinosaurs

Essential to modern life, around 40 per cent of the world's electricity comes from burning coal. The substance is used to make liquid fuel, plastics, concrete and even items such as head lice shampoo.

You might expect coal to be a high-tech material, because it has many sophisticated applications. But coal is simply a rock made from fossilised plants that died in swamps up to 100 million years before the first dinosaurs. Prehistoric plants captured energy from the Sun during their lives and locked it up as carbon in coal. We burn coal in power stations to release this ancient solar energy. This is why coal is sometimes called 'buried sunshine'.

Coal is mainly carbon and water. Carbon-rich coals contain little water and release lots of energy when burned. Low-carbon coals spent less time buried underground and contain more water and impurities. Coal 'rank' or quality depends on water and carbon content. There are four ranks: lignite, sub-bituminous, bituminous and anthracite. Up to ten per cent of a coal's weight comprises of sulphur. Modern power stations stop sulphur reaching the atmosphere.

All the fossil fuels we burn – coal, oil and gas – are the carbon-rich remains of prehistoric organisms. We describe fossil fuels as 'non-renewable' because these ancient stores of energy take millions of years to replenish once used. Rapidly releasing carbon from storage also pollutes the atmosphere. A byproduct of burning coal is carbon dioxide gas, a major cause of global warming.

When will Earth's coal run out?

No one knows exactly when we'll run out of coal, but its use has skyrocketed during the last 200 years. We used a whopping 6.8 billion tons – that's the approximate weight of 4 billion cars – in 2009 alone. Around 860 billion tons of coal remains unmined and major coal producers estimate supplies will last around 130 years at current rates.

Despite this estimate we can't be sure that coal won't run out sooner, as the world's remaining coal may turn out to be hard to reach or bad quality. Worse still, we're uncertain how much coal is buried. India, for example, overestimated its coal reserves by 36 billion tons in 2003. Alternatively, we may develop better sources of energy, stop using coal and never run out.

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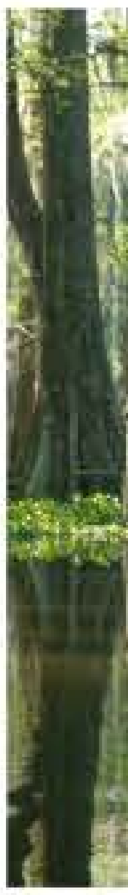
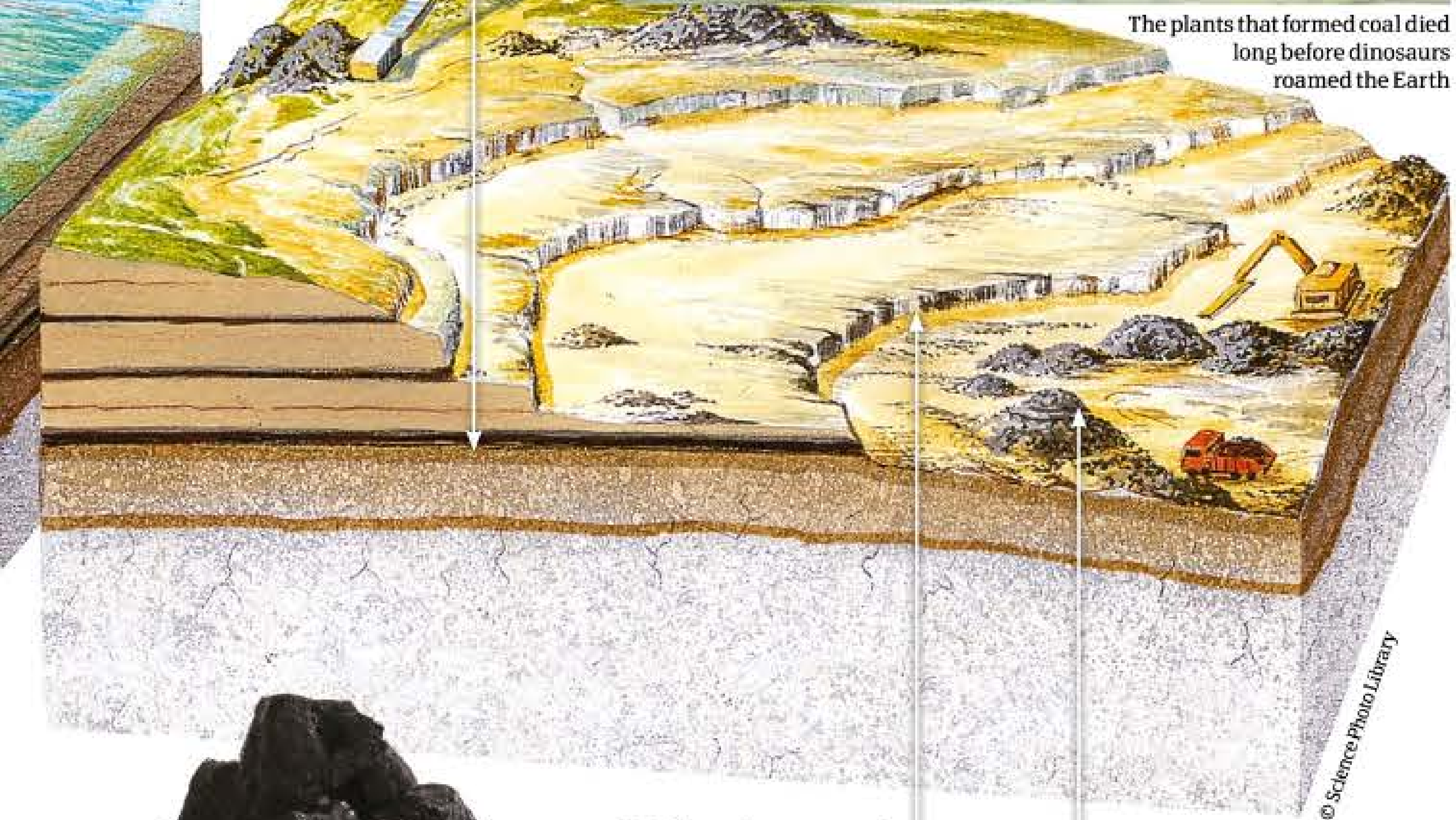


Coal formation

© Thinkstock

The plants that formed coal died long before dinosaurs roamed the Earth



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5. Lignite

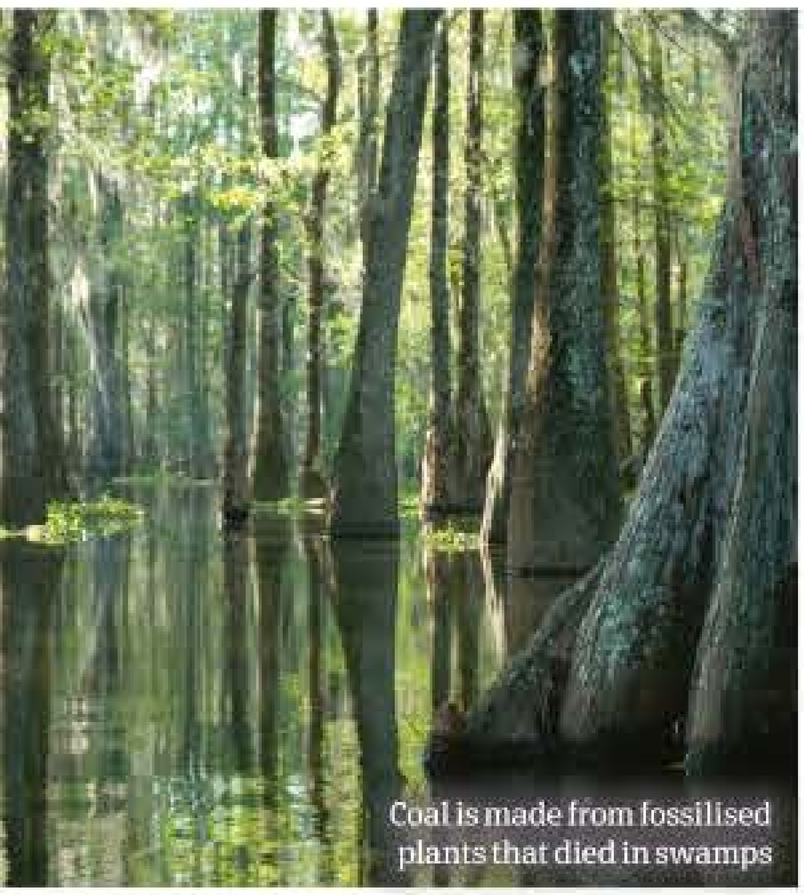
The peat is crushed and water is squeezed out by the weight of overlying sediments. Eventually, heat and pressure underground turns the peat into a soft, brown coal called lignite.

6. Bituminous and anthracite coal

Continued heat and pressure turn lignite into soft, black bituminous coal and hard, lustrous anthracite. These coals are richer in carbon than lignite because impurities and water are squeezed out.

7. Open-pit coal mine

Millions of years after plants died in the swamp, humans dig coal from the ground. Coal is dug from an open pit when it's found near the surface.



Coal is made from fossilised plants that died in swamps

Specialised coal-mining equipment is used to extract coal from the ground

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Wind turbines produce electricity

Energy for the future

We can't power our civilisation with ancient plants forever. In the future, we'll harness energy sources that don't run out in human lifetimes. An example is capturing the Sun's vast energy with light-gathering solar panels. Covering one per cent of the Sahara Desert with panels could generate enough energy to power the world.

Solar energy fuels the Earth's water cycle, which keeps rivers rushing downhill. This fast-moving water can spin propellers and generate electricity. Tide and bobbing wave movements can also drive electricity generators. Movements of the Moon, Sun and Earth cause tides and won't stop anytime soon.

Wind turbines are a familiar sight on breezy hills and huge turbine farms can also be built out at sea. The wind spins the turbine blades to generate electricity. Another energy source is the Earth's core, which is as hot as the Sun's surface. This heat can warm homes or generate electricity.

Coal will be replaced by solar panels in the future

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What are fossils?

Obliterating the traditional perception of the origins and evolution of life on Earth, fossils grant us unique snapshots of what once lived on our ever-changing planet

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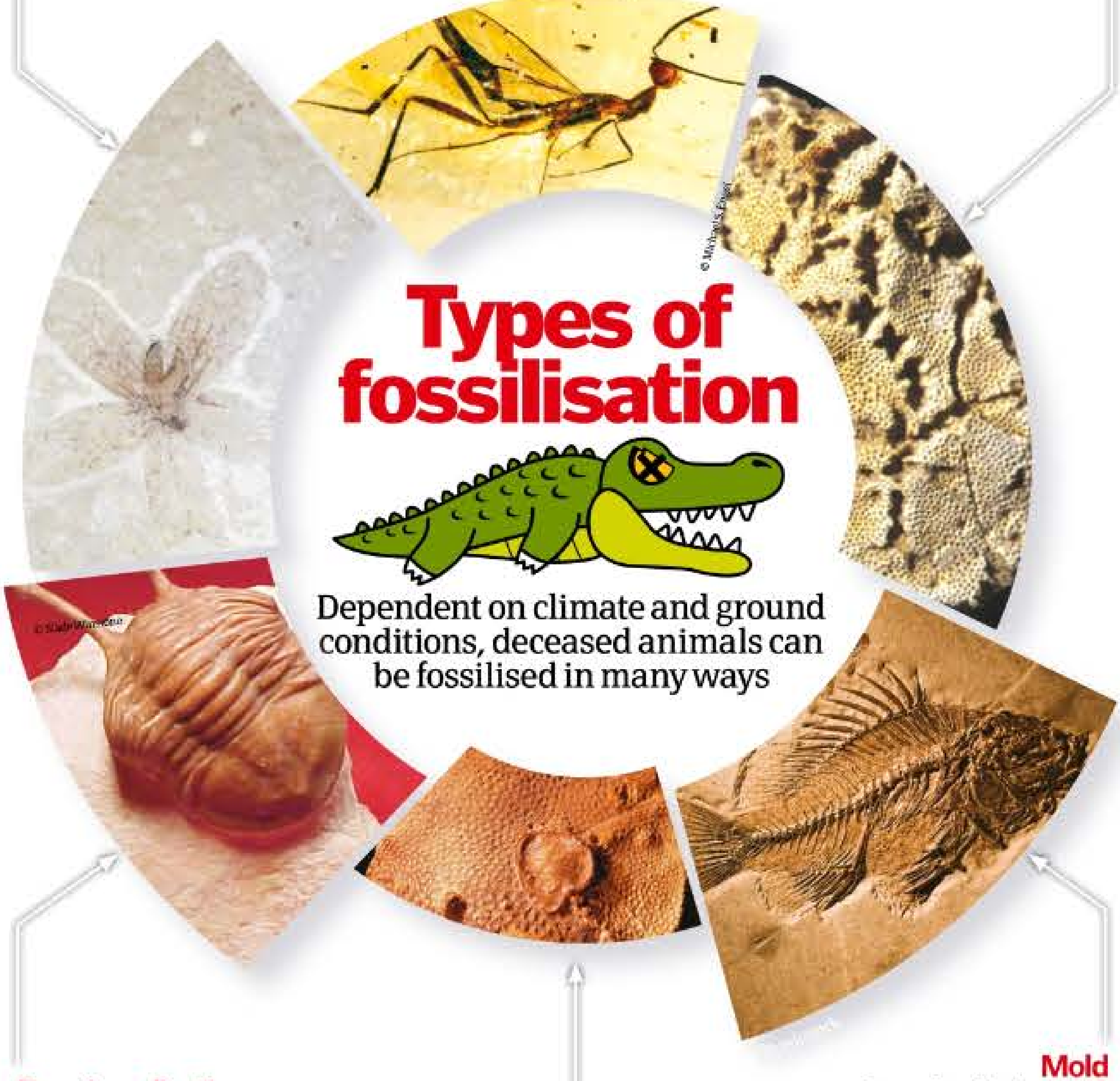
DID YOU KNOW? *Fossils are useful in targeting mineral fuels, indicating the stratigraphic position of coal streams*

Types of fossilisation

Dependent on climate and ground conditions, deceased animals can be fossilised in many ways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Adpression
A form of fossilisation caused by compression within sedimentary rock. This type of fossilisation occurs mainly where fine sediment is deposited frequently, such as along rivers. Many fossilised plants are formed this way.

Resin
Referred to as amber, fossil resin is a natural polymer excreted by trees and plants. As it is sticky and soft when produced, small invertebrates such as insects and spiders are often trapped and sealed within resin, preserving their form.

Bioimmuration
Bioimmuration is a type of fossil that in its formation subsumes another organism, leaving an impression of it within the fossil. This type of fossilisation usually occurs between sessile skeletal organisms, such as oysters.

Permineralisation
A process in which mineral deposits form internal casts of organisms, permineralisation works when an animal dies and then is rapidly submerged with groundwater. The water fills the creature's lungs and empty spaces, before draining away leaving a mineral cast.

Recrystallisation
When a shelled creature's shell, bone or tissue maintains its original form but is replaced with a crystal – such as aragonite and calcite – then it is said to be recrystallised.

Mold
A type of fossilisation process similar to permineralisation, molds occur when an animal is completely dissolved or destroyed, leaving only an organism-shaped hole in the rock. Molds can turn into casts if they are then filled with minerals.

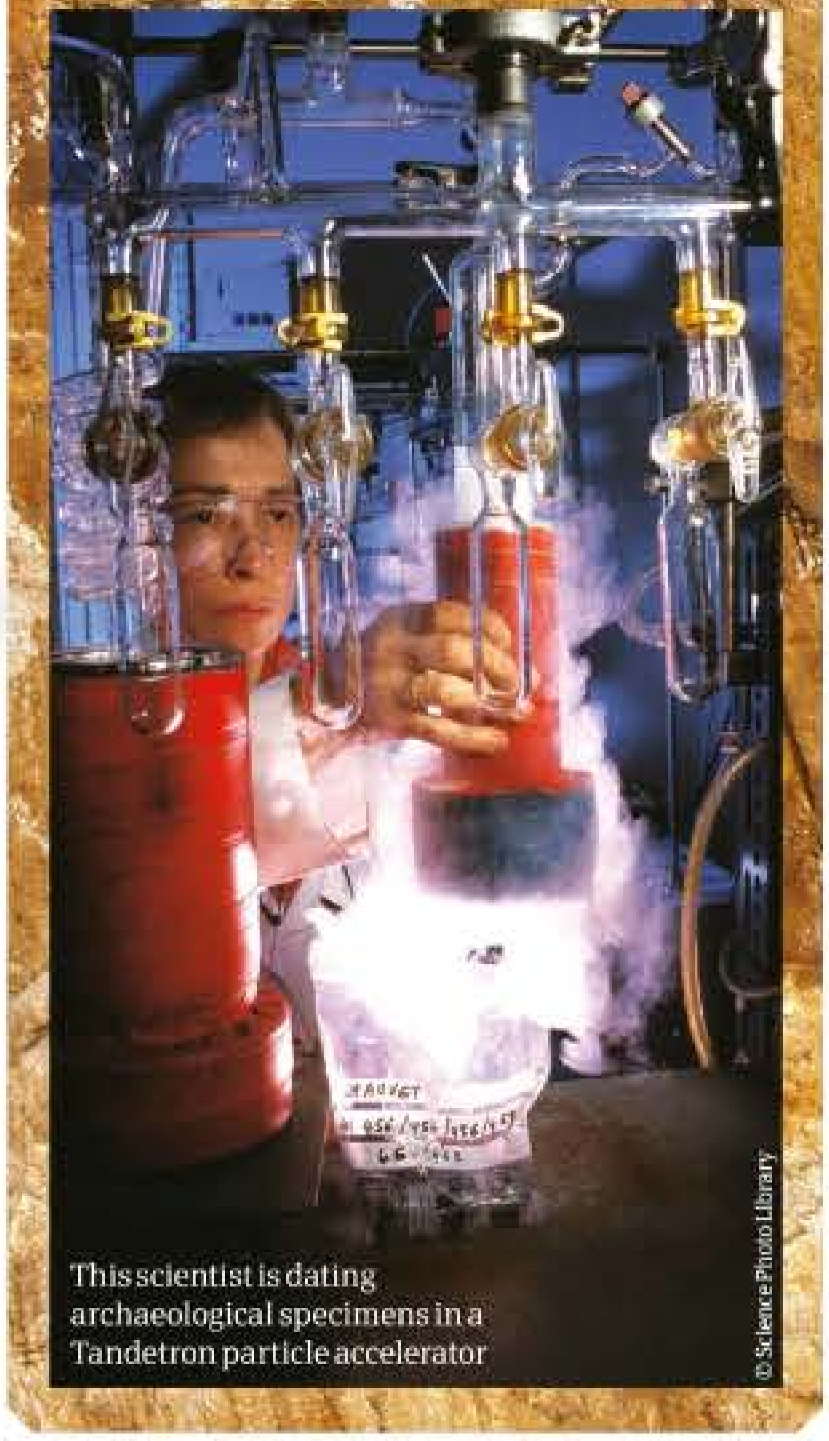
The origin of life on Earth is irrevocably trapped in deep time. The epic, fluid and countless beginnings, evolutions and extinctions are immeasurable to humankind; our chronology is fractured, the picture is incomplete. For while the diversity of life on Earth today is awe-inspiring, with animals living within the most extreme environments imaginable – environments we as humans brave every day in a effort to chart and understand where life begins and ends – it is but only a fraction of the total life Earth has seen inhabit it over geological time. Driven by the harsh realities of an ever-changing environment, Armageddon-level extinction events and the perpetual, ever-present force of natural selection, wondrous creatures with five eyes, fierce predators with foot-long fangs and massive creatures twice the size of a double-decker bus have long since ceased to exist. They're forgotten, buried by millions of years. Still, all is not lost. By exploiting Earth's natural processes and modern technology, scientists and palaeontologists have begun to unravel Earth's tree of life and, through the discovery and excavation of fossils – preserved remains and traces of past life in Earth's crust – piece the jigsaw back together.

The fossilisation of an animal can occur in a variety of ways (see 'Types of fossilisation' boxout) but, in general, it occurs when a recently deceased creature is rapidly buried by sediment or subsumed in an oxygen-deficient liquid. This has the effect of preserving parts of the creature – usually the harder, solid parts like its skeleton – often in the original, living form within the Earth's crust. The softer parts of fossilised creatures tend not to survive due to the speed of decay and their replacement by minerals contained in their sediment or liquid casing, a process that can leave casings and impressions of the animal that once lived, but not its remains. Importantly, however, creature fossilisation tends to

Carbon dating

A crucial tool for palaeontologists, carbon dating allows ancient fossils to be accurately dated

Carbon dating is a method of radioactive dating used by palaeontologists that utilises the radioactive isotope carbon-14 to determine the time since it died and was fossilised. When an organism dies it stops replacing carbon-14, which is present in every carbonaceous organism on Earth, leaving the existing carbon-14 to decay. Carbon-14 has a half-life (the time it takes a decaying object to decrease in radioactivity by 50 per cent) of 5,730 years, so by measuring the decayed levels of carbon-14 in a fossil, its time of death can be extrapolated and its geological age determined.


This scientist is dating archaeological specimens in a Tandetron particle accelerator

© Science Photo Library

be specific to the environmental conditions in which it lived – and these in themselves are indicative of certain time periods in Earth's geological history. For example, certain species of trilobite are only found in certain rock strata, which itself is identifiable by its materials and mineralogic composition. This allows palaeontologists to extrapolate the environmental conditions (hot, cold, dry, wet, etc) that the animal lived and died in and, in partnership with radiometric dating, assign a date to the fossil .

Interestingly, however, by studying the strata and the contained fossils over multiple layers, through a mixture of this form of palaeontology and phylogenetics (the study of evolutionary relationships between organism groups), scientists can chart the evolution of animals over geological time scales. A good example of this process is the now known transition of certain species of dinosaur into birds. Here, by dating and analysing specimens such as archaeopteryx – a famous dinosaur/bird transition fossil – both by strata and by radiometric methods, as well as recording their molecular and morphological data, scientists can then chart its progress through strata layers to the present day. In addition, by following the fossil record in this way, palaeontologists can also attribute the geophysical/chemical changes to the rise, fall or transition of any one animal/plant group, reading the sediment's composition and structural data. For example, the Cretaceous-Tertiary extinction event is identified in sedimentary strata by a sharp decline in species' diversity – notably non-avian dinosaurs – and increased calcium deposits from dead plants and plankton.

Excavating any discovered fossil in order to date and analyse it is a challenging, time-consuming process, which requires special tools and equipment. These include picks and shovels, trowels, whisks, hammers, dental drills and even explosives. There is also an accepted academic method all professional palaeontologists follow when preparing, removing and transporting any discovered fossil. First, the fossil is partially freed from the sedimentary matrix it is encased in and labelled, photographed and reported. Next, the overlying rock is removed using large tools up to a distance of 5-7.5 centimetres (two to three inches) from the fossil, before it is once again photographed. Then, depending on the stability of the fossil, it is coated with a thin glue via brush or aerosol in order to strengthen its structure, before being wrapped in a series of paper, bubble wrap and Hessian cloth. Finally, it is transported to the laboratory.

A europasaurus fossil is examined

© Nils Knoetschke

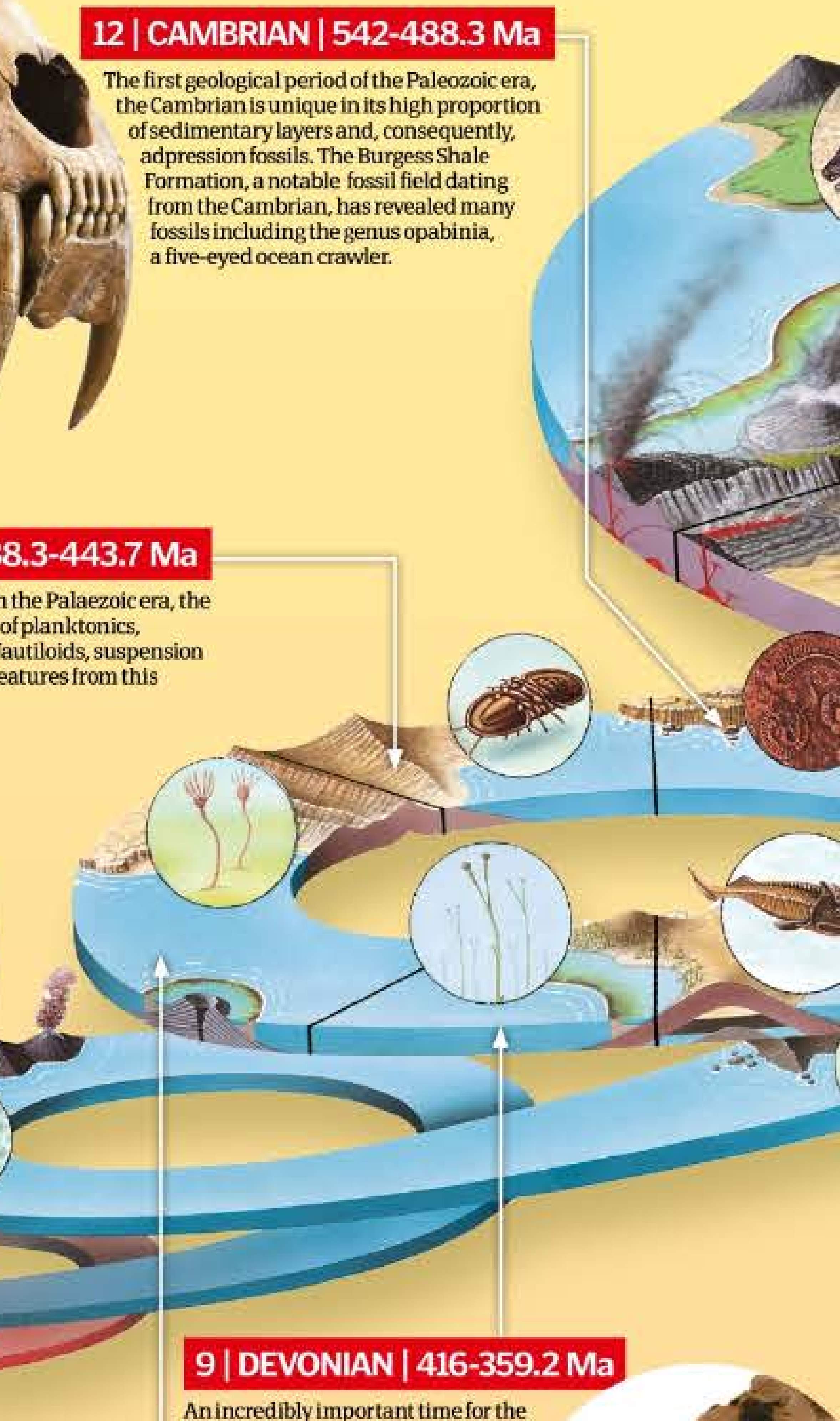
THE FOSSIL RECORD

By examining discovered fossils, it is possible to piece together a rough history of the development of life on Earth over a geological timescale

© Wallace69

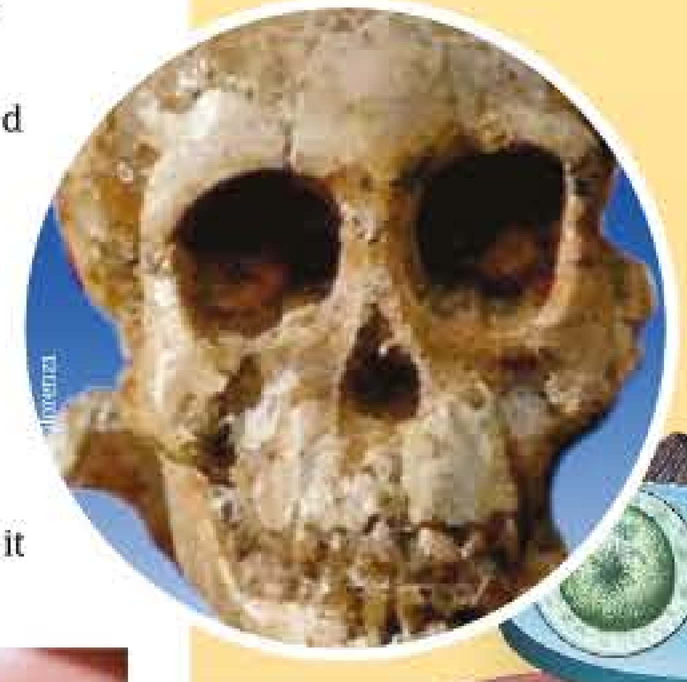
12 | CAMBRIAN | 542-488.3 Ma

The first geological period of the Paleozoic era, the Cambrian is unique in its high proportion of sedimentary layers and, consequently, adpression fossils. The Burgess Shale Formation, a notable fossil field dating from the Cambrian, has revealed many fossils including the genus opabinia, a five-eyed ocean crawler.



11 | ORDOVICIAN | 488.3-443.7 Ma

Boasting the highest sea levels on the Palaezoic era, the Ordovician saw the proliferation of planktonics, brachiopods and cephalopods. Nautiloids, suspension feeders, are among the largest creatures from this period to be discovered.



10 | SILURIAN | 443.7-416 Ma

With its base set at major extinction event at the end of the Ordovician, the silurian fossils found differ markedly from those that pre-date the period. Notable life developments include the first bony fish, and organisms with moveable jaws.

9 | DEVONIAN | 416-359.2 Ma

An incredibly important time for the development of life, the Devonian period has relinquished fossils demonstrating the evolution of the pectoral and pelvic fins of fish into legs. The first land-based creatures, tetrapods and arthopods, become entrenched and seed-bearing plants spread across dry lands. A notable find is the genus tiktaalik.

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3 | PALEOGENE | 65.5-23.03 Ma

The first period of the Cenozoic era, the Paleogene is notable for the rise of mammals as the dominant animal group on Earth, driven by the Cretaceous-Tertiary extinction event that wiped out the dinosaurs. The most important fossil to be discovered from this period is darwinius, a lemur-like creature uncovered from a shale quarry in Messel, Germany.

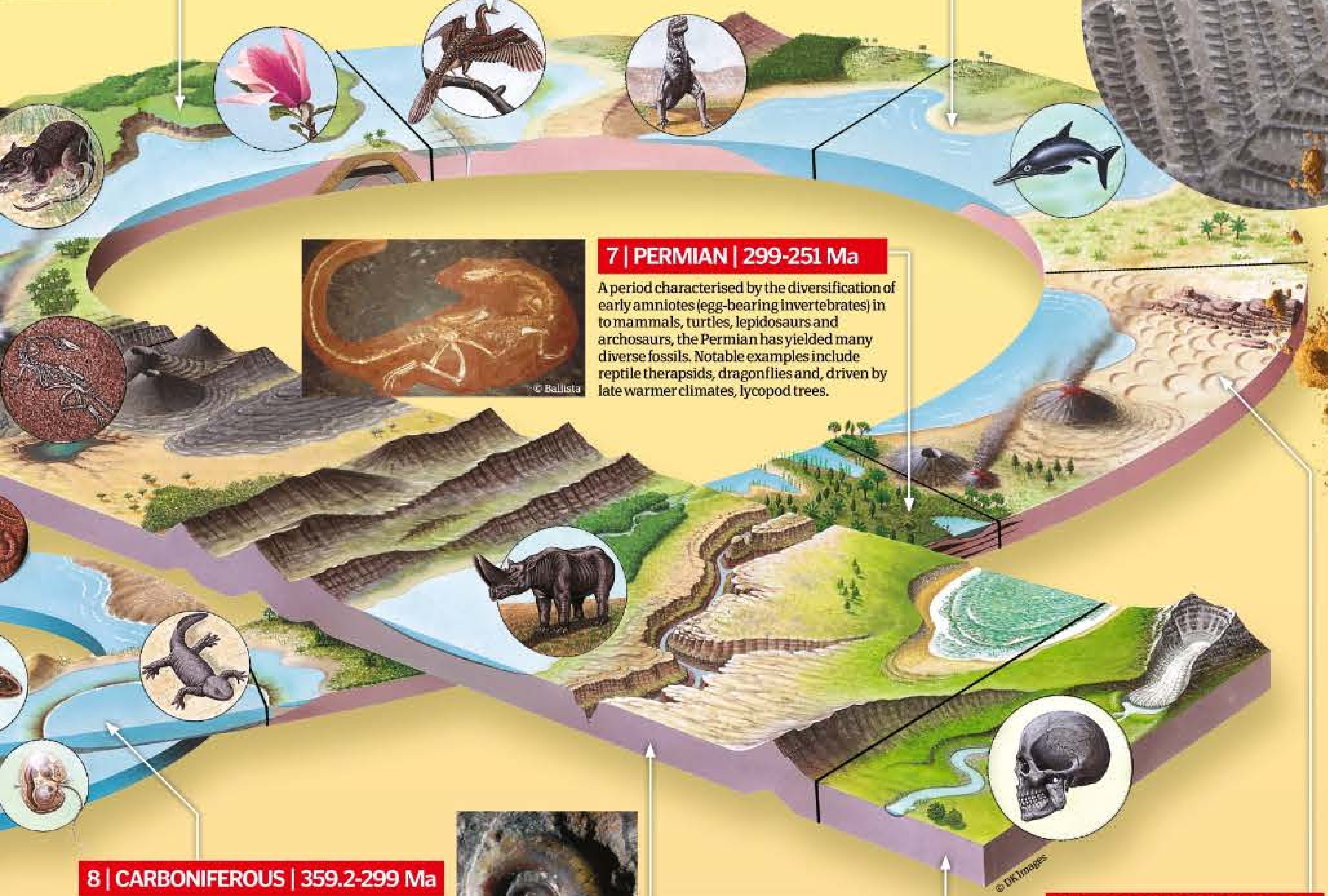
4 | CRETACEOUS | 145.5-65.5 Ma

© Petter Bøckman

Fossils discovered from the cretaceous indicate an explosion of insect diversification, with the first ants and grasshoppers evolving, as well as the dominance of large dinosaurs such as the colossal tyrannosaurus rex. Mammals increased in diversity, however remained small and largely marsupial.

5 | JURASSIC | 199.6-145.5 Ma

The period in Earth's history when the supercontinent Pangaea broke up in to the northern Laurasia and southern Gondwana, the Jurassic saw an explosion in marine and terrestrial life. The fossil record points to dinosaurs thriving, such as megalosaurus, an increase in large predatory fish like ichthyosaurus, as well as the evolution of the first birds – shown famously by the archaeopteryx fossil find.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7 | PERMIAN | 299-251 Ma

A period characterised by the diversification of early amniotes (egg-bearing invertebrates) in to mammals, turtles, lepidosaurs and archosaurs, the Permian has yielded many diverse fossils. Notable examples include reptile therapsids, dragonflies and, driven by late warmer climates, lycopod trees.

8 | CARBONIFEROUS | 359.2-299 Ma

A period of significant glaciation, the Carboniferous saw the development of ferns and conifers, bivalve molluscs and a wide-variety of basal tetrapods such as labyrinthodontia. Notable fossilised finds include the seed ferns pecopteris and neuropteris.

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2 | NEOGENE | 23.03-2.588 Ma

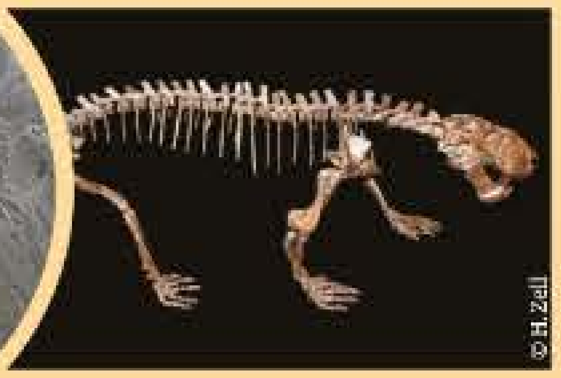
Covering 23 million years, the Neogene period's fossils show a marked development in mammals and birds, with many hominin remains excavated. The extinct hominid australopithecus afarensis – a common ancestor of the genus homo (that of modern humans) – is one of the most notable fossil finds, as exemplified in the specimens Lucy and Selam.

1 | QUATERNARY | 2.588-0.00 Ma

The most recent period in Earth's history, the Quaternary is characterised by major changes in climate, as well as the evolution and dispersement of modern humans. Due to the rapid changes in environment and climate (ie ice ages), many larger mammal fossils have been discovered, including those of mammoths and sabre-toothed cats.

6 | TRIASSIC | 250-200 Ma

Beginning and ending with an extinction event, the Triassic period's fossils show the evolution of the first dinosaurs such as Coelophysis, a small carnivorous biped animal. Fossil evidence also shows the development of modern corals and reefs.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AMAZING ANIMALS

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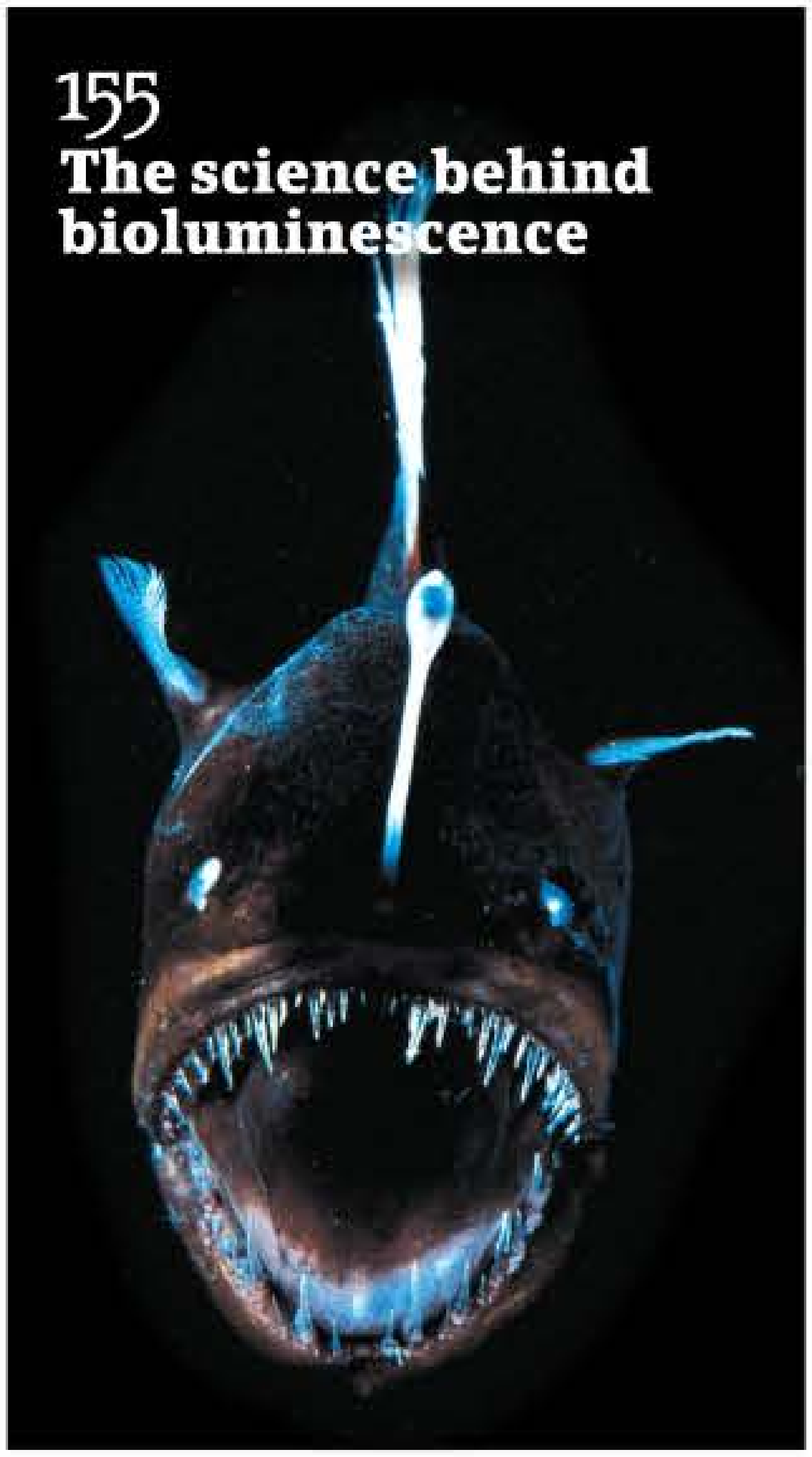
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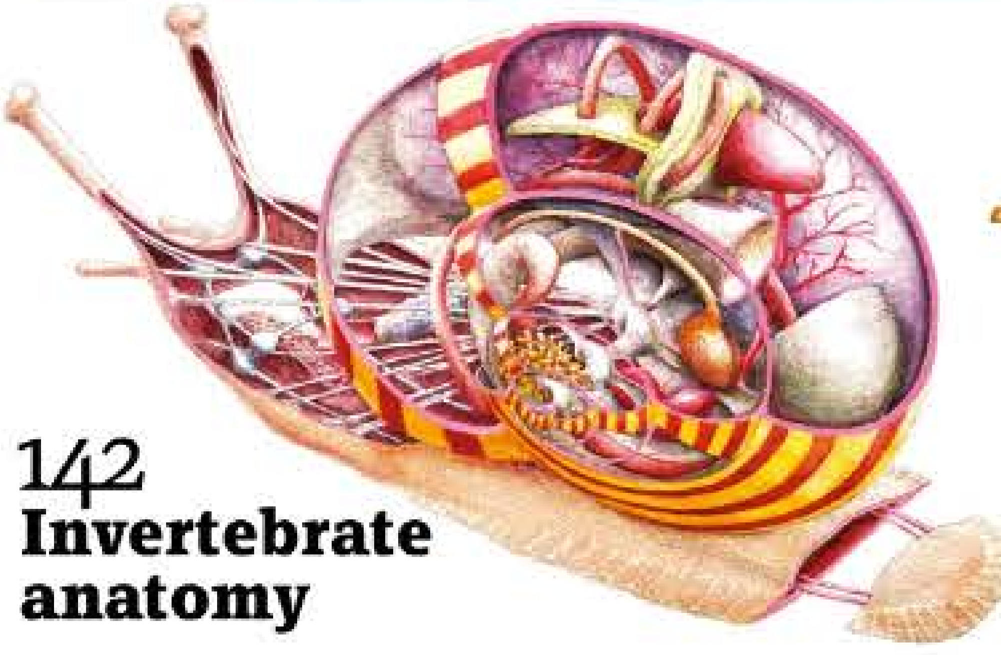
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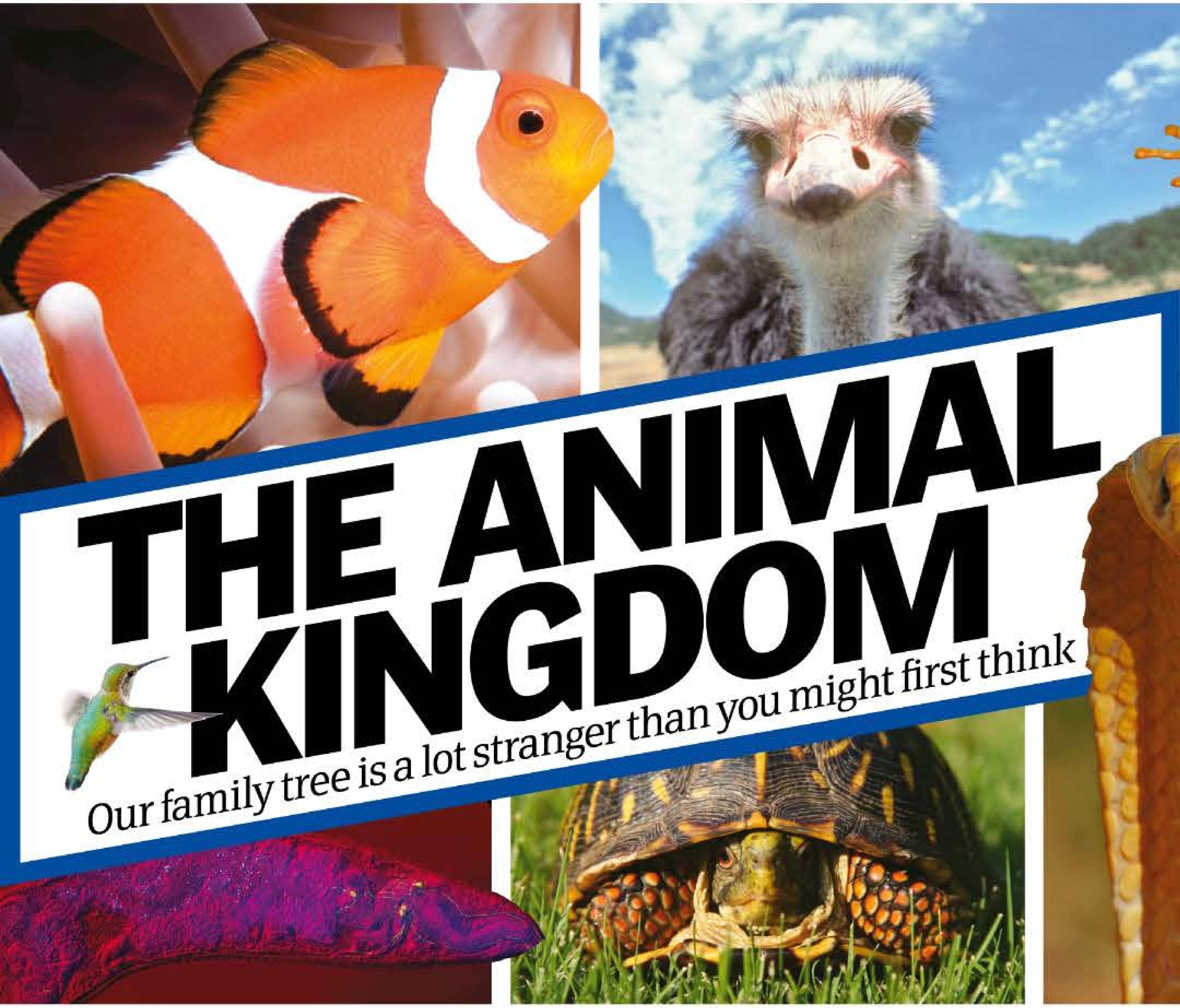


THE ANIMAL KINGDOM

Our family tree is a lot stranger than you might first think

Major phyla

The animal kingdom has approximately 35 phyla. Discover nine of the main ones now…

Chordata

Animals with a notochord (primitive backbone). Vertebrates are chordates but they only have a notochord as embryos. After that it develops into a true spine.

Arthropoda

A hard exoskeleton with jointed legs and a body divided into segments. It is the most diverse phylum, with well over a million known species on Earth.

Mollusca

Molluscs have a mantle cavity for breathing, which is often protected by a shell. But the shell can be spiral, hinged or missing altogether – eg cephalopods.

Nematoda

Thread-like worms ranging from microscopic to several metres in length. They have a distinct head, with teeth or a stabbing syringe, and a simple intestine.

DID YOU KNOW? *Four out of every five animals alive today are nematode worms*

Sort your life out!

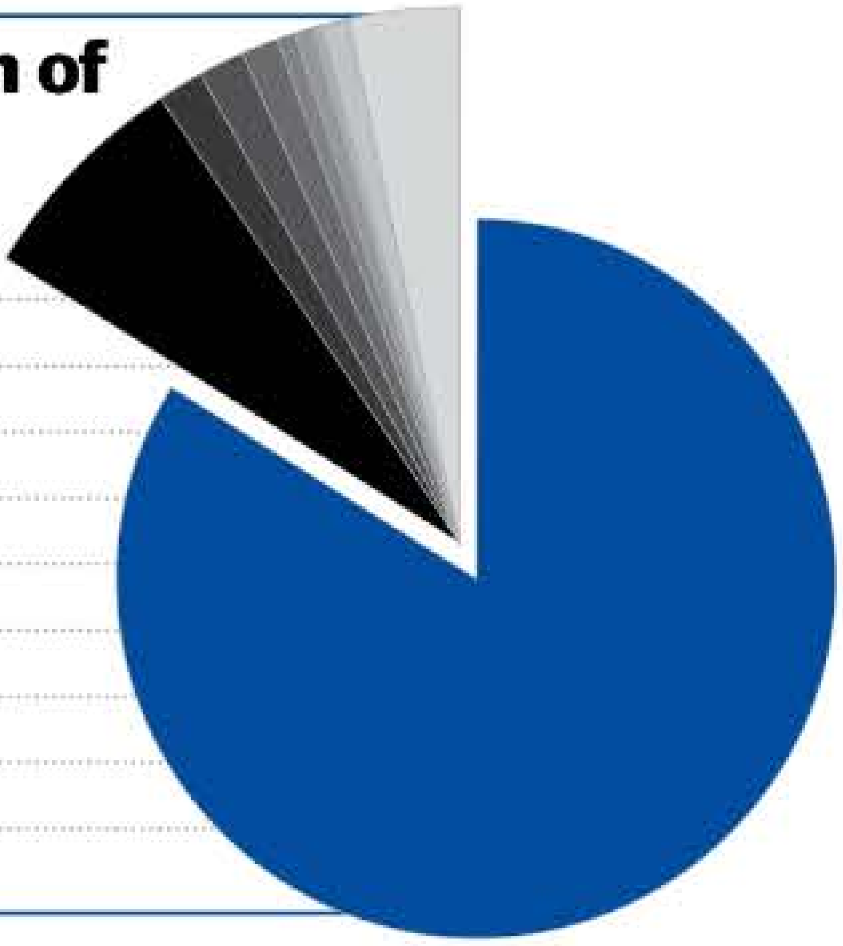
A brief guide to how we structure all life on Earth

- Domain
- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

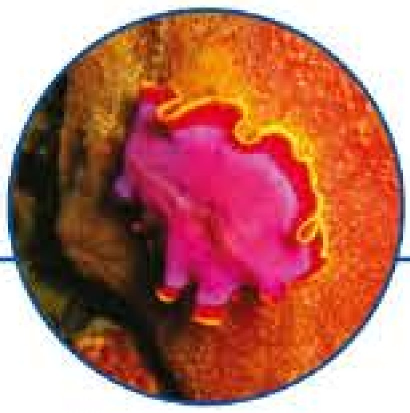
In the fourth century BCE, Aristotle divided the world into animals and plants. The word 'animal' comes from the Latin animalis and means 'having breath'. Animals were all the living creatures that moved and breathed, while plants were the ones that stayed put. For over 2,000 years the living world was divided into just these two kingdoms. After the invention of the microscope and later the electron microscope, scientists came to recognise that single-celled organisms couldn't really be classified as animals *or* plants. Bacteria and another type of single-celled organism called Archaea are now counted as fundamentally different groups of their own. That leaves animals, plants and fungi as fairly recent evolutionary offshoots from the larger group of organisms with a cell nucleus, called the eukaryotes.

The animal kingdom consists of the eukaryotes that are multicellular. Their cells are specialised into different types and grouped into tissues that perform different functions. Animals are divided into major groups, known as phyla, and each phylum has animals with a radically different arrangement of these tissues. All animals obtain their energy by eating other organisms, so they need some way of catching and digesting these organisms. But there are a lot of ways of solving this problem. So, for example, the echinoderms, which include starfish, are all radially symmetrical, while the arthropods all have rigid, jointed exoskeletons. There are nine main phyla, with a couple of dozen much smaller ones containing all the odd and difficult to classify creatures. Indeed, between them,

What proportion of species belongs to each group?



- ■ **Arthropoda:** 83.7%
- ■ **Mollusca:** 6.8%
- ■ **Chordata:** 3.6%
- ■ **Nematoda:** 1.4%
- ■ **Platyhelminthes:** 1.4%
- ■ **Annelida:** 1.0%
- ■ **Cnidaria:** 0.6%
- ■ **Echinodermata:** 0.5%
- ■ **Porifera:** 0.3%
- ■ **Others:** 0.7%



Platyhelminthes

Very simple flatworms with no specialised circulation or respiratory system. The digestive cavity has a single opening serving as both mouth and anus.

Annelida

Roundworms with bodies built from repeating segments. Each segment has the same internal organs and may have bristles or appendages to help them move.

Cnidaria

A body formed from two layers of cells sandwiching a layer of jelly in between. The outer layer has specialised stinging cells (cnidocytes) for catching prey.

Echinodermata

Unusual because of their radial symmetry – usually fivefold but occasionally seven or more. Their skin is covered with armoured plates or spines.

Porifera

Very simple animals with no nervous, digestive or circulatory systems. Instead, nutrients and waste are carried through their porous bodies by water currents.

these nine groups account for more than 99 per cent of all animal species alive today.

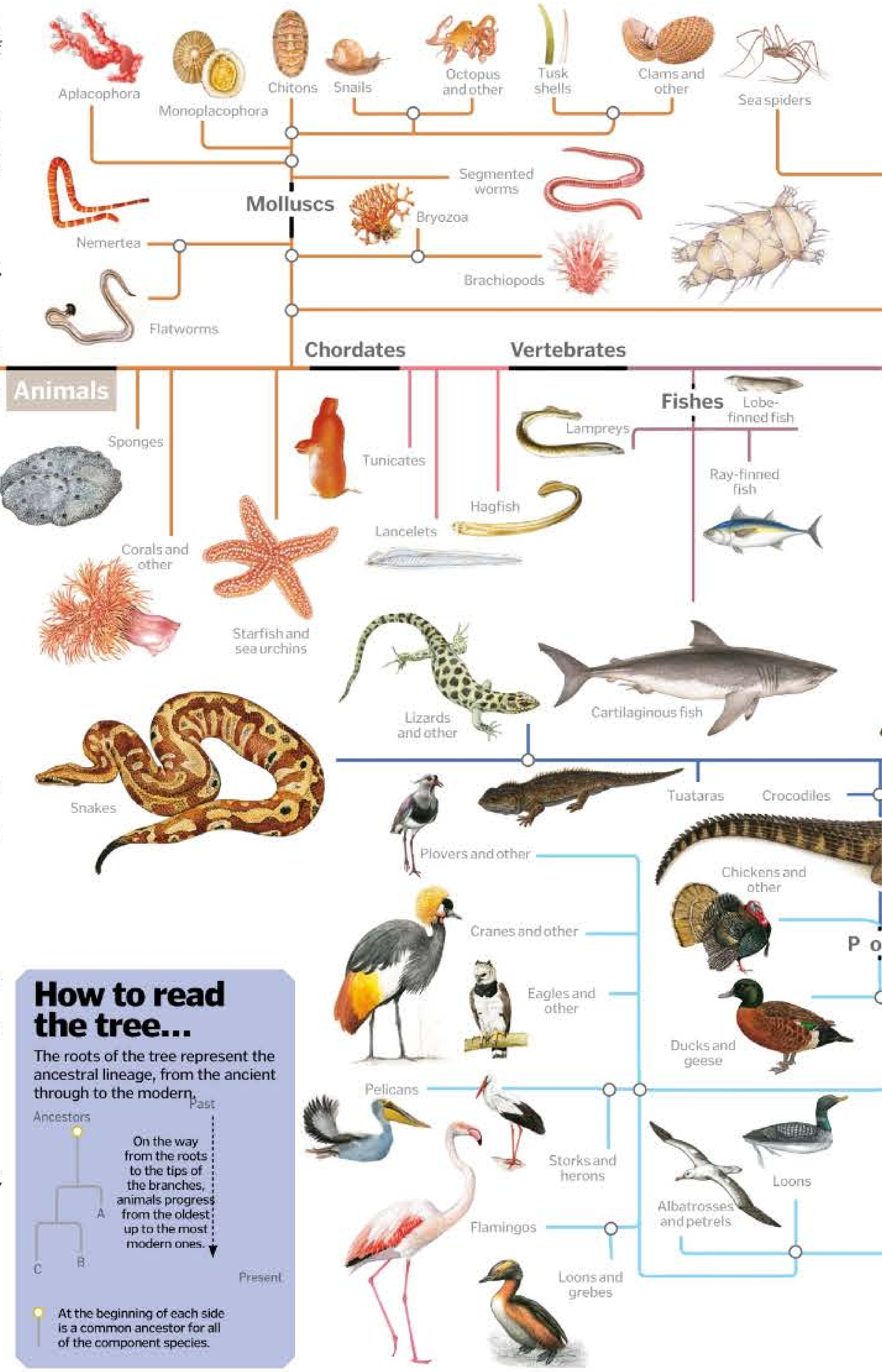
At a first glance, some of the groups seem very similar. The annelids are segmented worms, while the nematodes are roundworms and the platyhelminths are flatworms. Why aren't they all just grouped together as worms? Even a brief look at their internal structure shows the reason. Flatworms have bodies that are left/right symmetrical and their digestive system is just a simple sock shape with only one opening. Roundworms have a radially symmetrical head and a tubular digestive system that has an opening at each end. Annelids are even more sophisticated internally, with bodies made of repeating segments and distinct organ systems. The characteristics that separate these three groups of animals are far more important than the things that link them together. Being called a 'worm' just means that your body is long and thin with no legs, after all. That also applies to a snake, and snakes clearly aren't worms.

Snakes are vertebrates, of course, but surprisingly, the vertebrates aren't considered a phylum of their own. Instead they are grouped within the chordates. That's because the backbone itself isn't the most important distinguishing feature; rather it's the nerve cord running the length of the body that the backbone protects. There are some simple fish-like creatures that have a spinal cord even though they don't have bony vertebrae. The spinal cord was the adaptation that led to the development of our complex nervous systems, and it is such an important feature that all creatures with a spinal cord are grouped together in the chordates. However, 97 per cent of all animals are still invertebrates. The vertebrate animals – which include us – are just a subgroup of a single phylum.

So which is the largest of the groups then? It depends on how you count it. In terms of the sheer number of individuals, the nematodes are the most numerous. But they are also very small, so it's not an entirely fair measure. There are over a million nematodes in every square metre of soil! Biologists generally prefer to look at the number of different species in a group. This is a way of measuring how successful a particular body plan has been in adapting to different environments. By that measure, the arthropods are currently in the lead – around 84 per cent of all known species are arthropods,

"Our system of naming animals was devised by Carl Linnaeus"

The animal tree of life

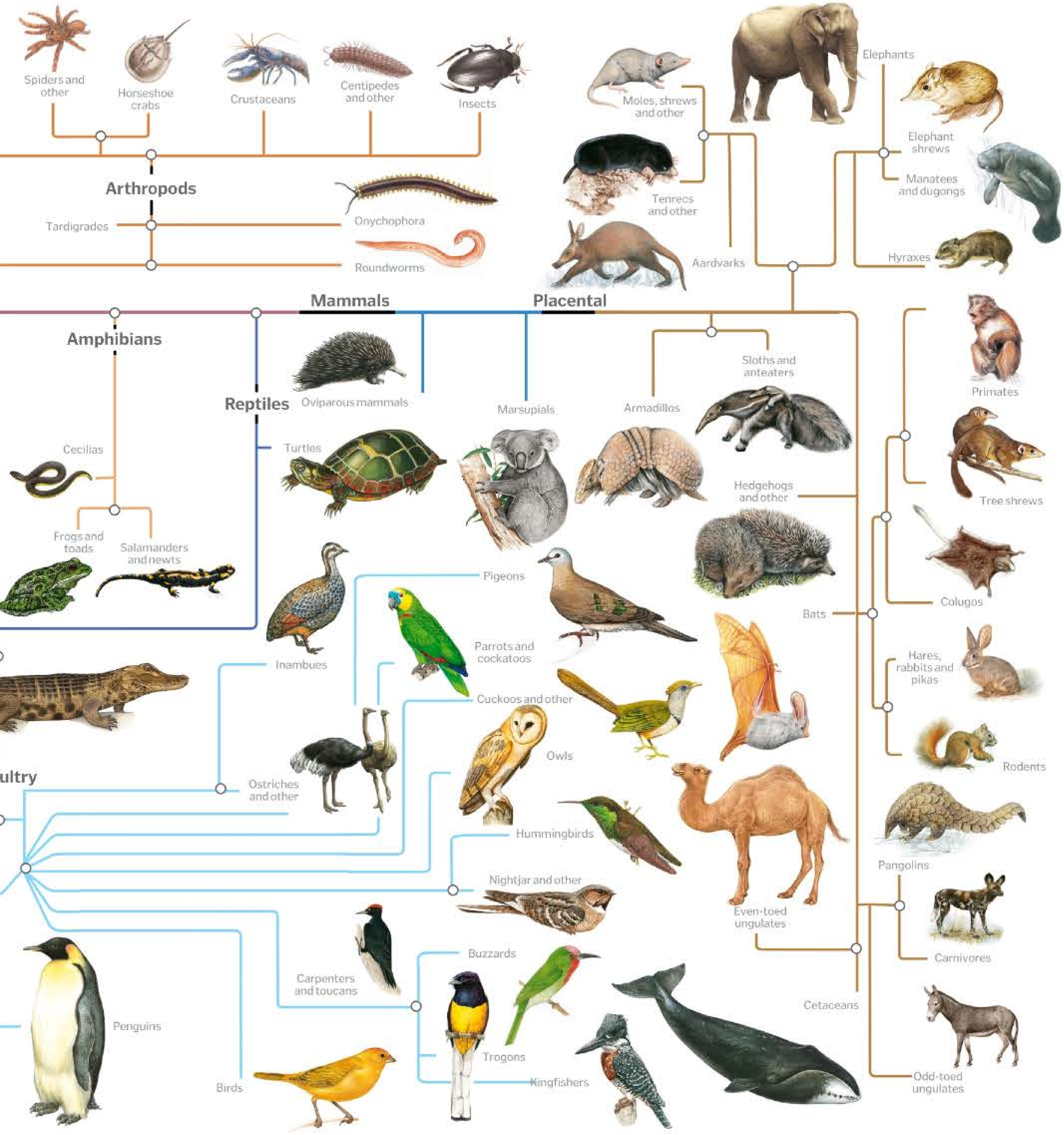


How to read the tree...

The roots of the tree represent the ancestral lineage, from the ancient through to the modern.

On the way from the roots to the tips of the branches, animals progress from the oldest up to the most modern ones.

At the beginning of each side is a common ancestor for all of the component species.


Spiders and other
Horseshoe crabs
Crustaceans
Centipedes and other
Insects
Arthropods
Tardigrades
Onychophora
Roundworms
Moles, shrews and other
Elephants
Elephant shrews
Tenrecs and other
Manatees and dugongs
Aardvarks
Hyraxes
Mammals
Placental
Amphibians
Reptiles
Oviparous mammals
Marsupials
Armadillos
Sloths and anteaters
Primates
Cecilias
Turtles
Hedgehogs and other
Tree shrews
Frogs and toads
Salamanders and newts
Pigeons
Colugos
Bats
Inambues
Parrots and cockatoos
Hares, rabbits and pikas
Cuckoos and other
Owls
Rodents
ultry
Ostriches and other
Hummingbirds
Pangolins
Nightjar and other
Even-toed ungulates
Buzzards
Carnivores
Carpenters and toucans
Cetaceans
Penguins
Trogons
Birds
Kingfishers
Odd-toed ungulates

mostly in the subgroup of insects. But this is also a somewhat misleading statistic. There are a lot of species still waiting to be discovered and identified. Insects are easy to catch, preserve well and most of their distinguishing characteristics can be seen with nothing more sophisticated than a magnifying glass. Nematodes, on the other hand, are mostly microscopic and, although tens of thousands of species have been described so far, they all look very similar. It's possible that there are as many as a million more species of nematode out there waiting to be discovered and named. If so, this would make them roughly level with the arthropods in species numbers.

The system of naming animals that we use today was devised by the Swedish naturalist Carl Linnaeus (or Carl von Linné as he was known after he was made a noble). He used a two-part name to uniquely identify every animal and plant. It consists of a genus and a species, like a surname and a first name, except that it is written with the genus first and then the species. So the chimpanzee belongs to the genus Pan and the species troglodytes. The name is often written in italics with the genus capitalised: Pan troglodytes. The bonobo chimp, meanwhile, belongs to the same genus but has a different species: Pan paniscus.

Above the level of genus, animals are grouped together into families, then orders, then classes, then phyla. So, for example, the dromedary camel belongs to the kingdom of animals, the phylum of chordates, the class of mammals, the order Artiodactyla, the family Camelidae, the genus Camelus and the species dromedarius. The higher groupings are used to show the evolutionary relationships between animals, but Camelus dromedarius is all you need to precisely identify which organism you are talking about, from the entirety of the natural world. The genus name is often abbreviated, particularly when it is long. So the bacterium E coli is actually Escherichia coli.

In general, the division of the animal kingdom into groups reflects how closely related the animals in that group are to each other, but there are exceptions. Birds are actually more closely related to crocodiles than snakes are, and yet both crocodiles and snakes are in the class of reptiles, and birds have their own class: Aves. This is because birds all have lots of physical resemblances to each other that make them feel like a coherent group, whereas reptiles are actually a grab-bag class with only superficial physical resemblances. The reptiles are really just the leftover vertebrates that aren't birds, mammals or amphibians.

Species though are a much more fundamental unit of classification. Animals in

Invertebrate anatomy

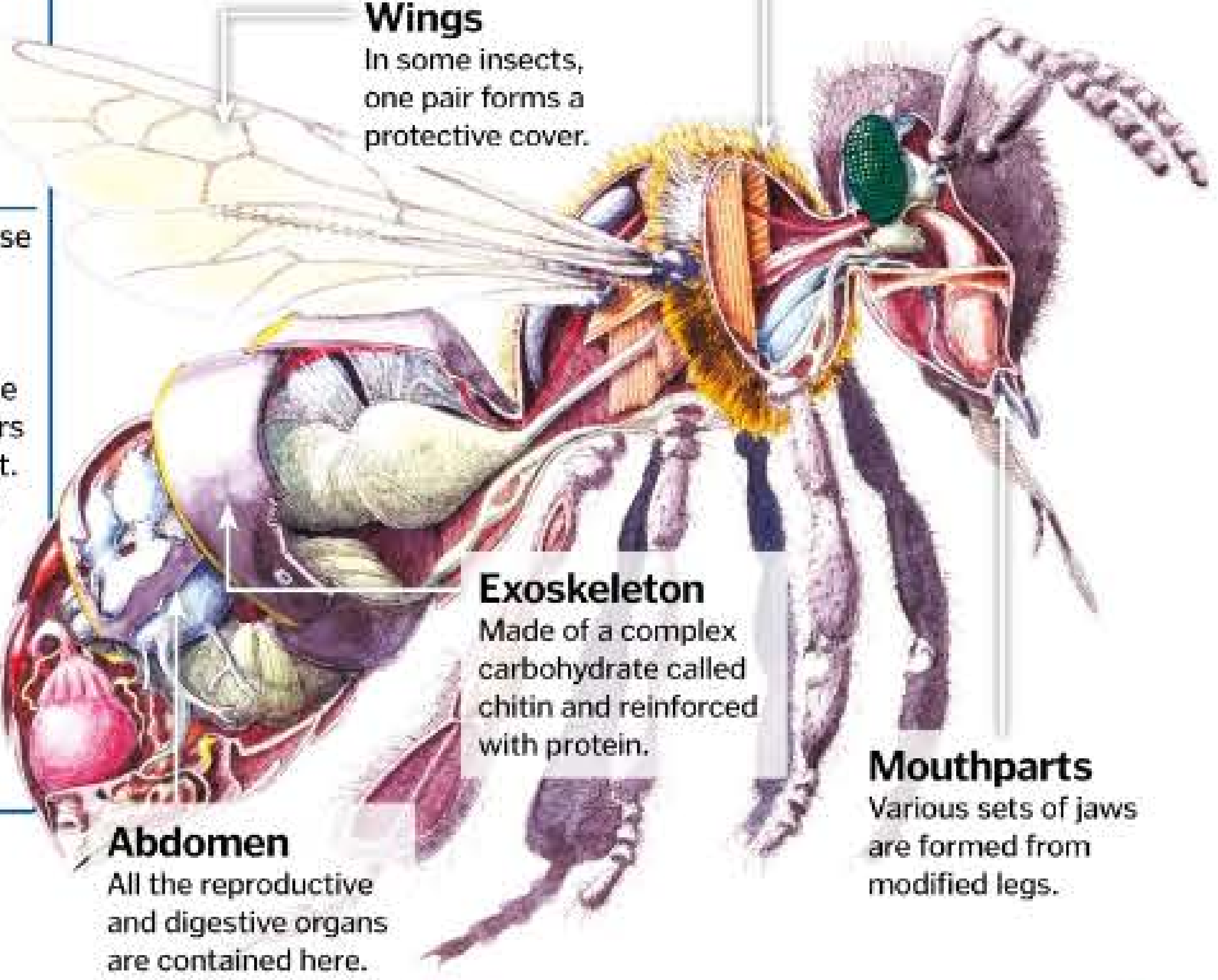
United by their lack of backbone, what are invertebrates really like?

INSECTS

Phylum: Arthropoda

Phylum also includes: Spiders, scorpions, centipedes, millipedes, crustaceans

Info: Insects are the most diverse group of animals on Earth. It's possible that 90 per cent of all species are insects. They have three body segments, with three pairs of legs and one or two pairs of wings on the middle segment. The whole body is protected by a waterproof, rigid exoskeleton that also provides an attachment point for the muscles. Insects have a larval form that is often aquatic but very few insects live in saltwater.



Hairs
Sensory bristles allow touch sensation through the rigid exoskeleton.

Wings
In some insects, one pair forms a protective cover.

Exoskeleton
Made of a complex carbohydrate called chitin and reinforced with protein.

Mouthparts
Various sets of jaws are formed from modified legs.

Abdomen
All the reproductive and digestive organs are contained here.

SPONGES

Phylum: Porifera

Phylum also includes: Calcareous sponges, glass sponges

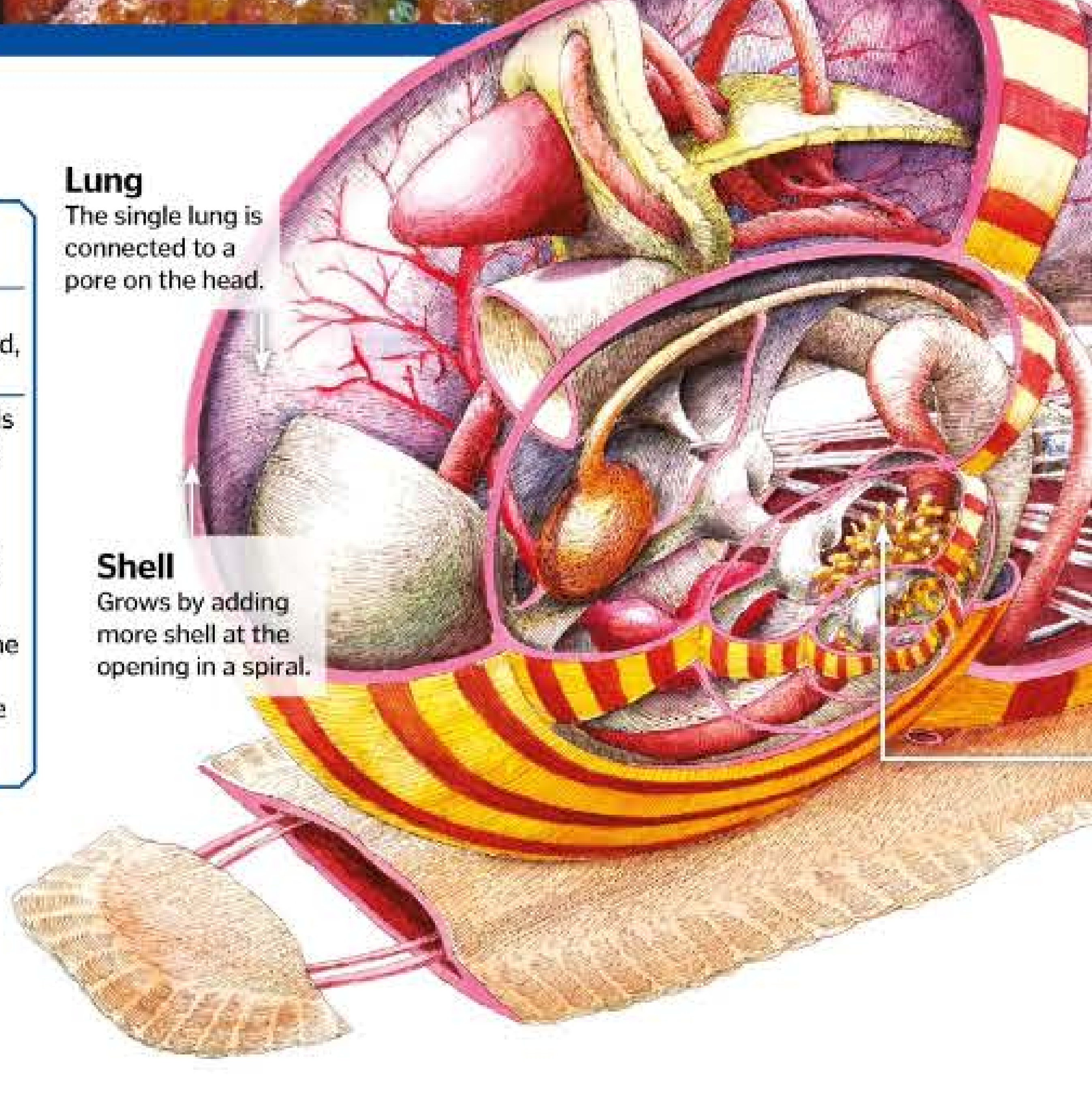
Info: Most sponges belong to the class Demospongiae. Although a sponge has different cell types, the body structure is very loosely organised. Amazingly if you pass a sponge through a sieve to separate the cells, they will reform into sponges. Most sponges photosynthesise using symbiotic bacteria, though a few prey on plankton and even shrimp.

GASTROPODS

Phylum: Mollusca

Phylum also includes: Clams, razorshells, oysters, squid, octopuses

Info: Gastropods are slugs, snails and limpets. Snails have a spiral shell large enough for them to retreat into, to prevent them drying out or being eaten. They use a chainsaw arrangement of microscopic teeth (a radula) to graze on algae and plants. Marine snails use their radula plus secreted acid to drill through the shells of other molluscs.



Lung
The single lung is connected to a pore on the head.

Shell
Grows by adding more shell at the opening in a spiral.

DID YOU KNOW? *The total weight of all the ants in the world is the same as the total weight of all humans*

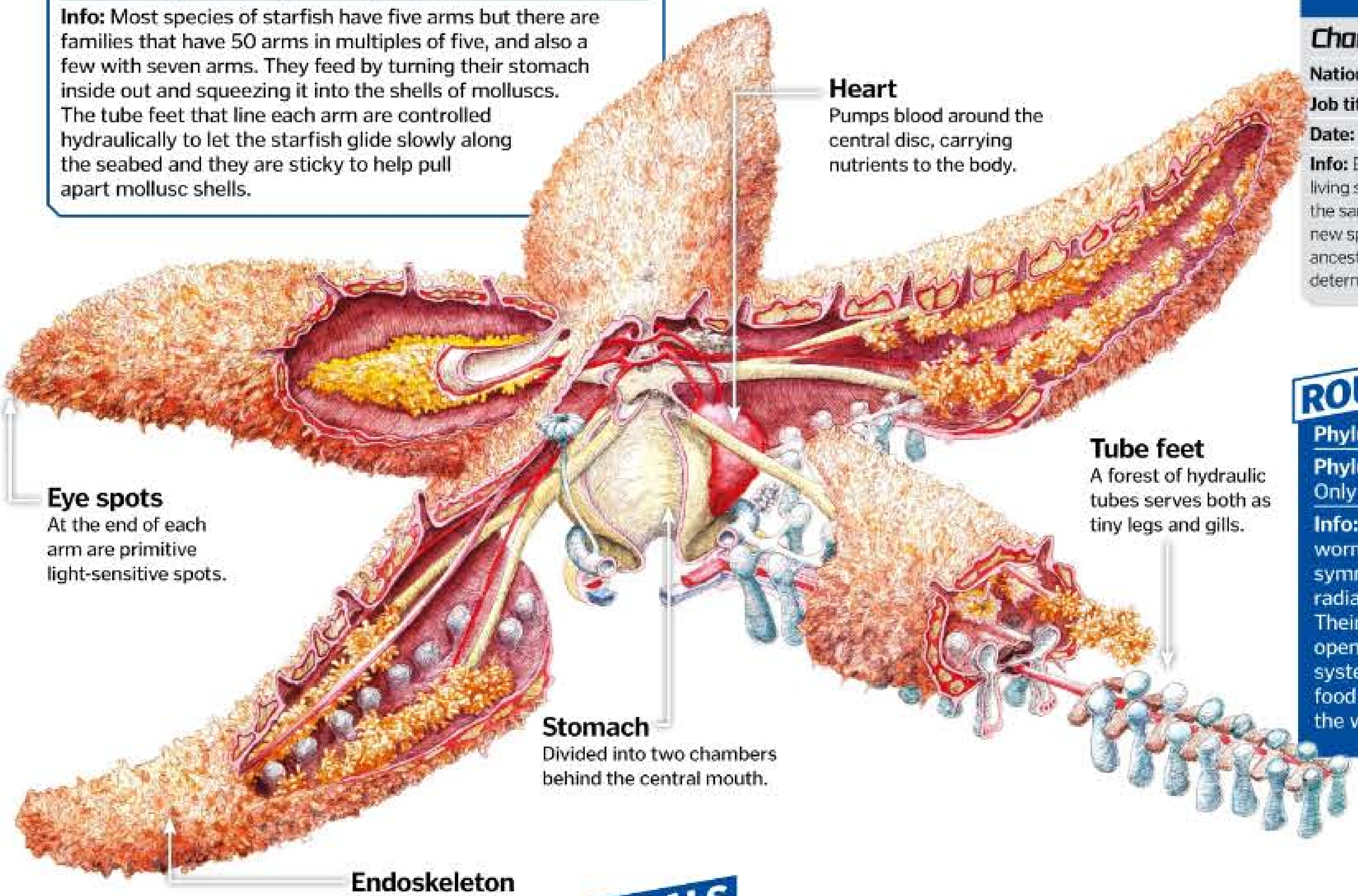
SEA STARS

Phylum: Echinodermata

Phylum also includes:
Brittle stars, sea urchins, sea lilies, sea cucumbers

Info: Most species of starfish have five arms but there are families that have 50 arms in multiples of five, and also a few with seven arms. They feed by turning their stomach inside out and squeezing it into the shells of molluscs. The tube feet that line each arm are controlled hydraulically to let the starfish glide slowly along the seabed and they are sticky to help pull apart mollusc shells.

> "Sea stars feed by turning their stomach inside out"



Heart
Pumps blood around the central disc, carrying nutrients to the body.

Eye spots
At the end of each arm are primitive light-sensitive spots.

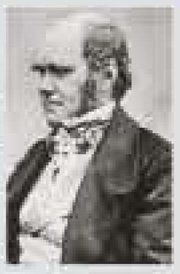
Tube feet
A forest of hydraulic tubes serves both as tiny legs and gills.

Stomach
Divided into two chambers behind the central mouth.

Endoskeleton
Calcium carbonate spines or studs cover the skin for protection.

KEY PLAYER

Charles Darwin



Nationality: British

Job title: Naturalist

Date: 1809-1882

Info: Established all living species are part of the same family tree. Evolution causes new species to branch away from ancestral ones. Natural selection determines survival and extinction.

ROUNDWORMS

Phylum: Nematoda

Phylum also includes:
Only roundworms

Info: Nematodes are thin worms with a bilaterally symmetrical body and a radially symmetrical head. Their digestive system has an opening at each end with a system of valves that pushes food through the intestine as the worm wriggles around.

CORALS

Phylum: Cnidaria

Phylum also includes:
Jellyfish, sea wasps, freshwater hydra

Info: Corals and sea anemones belong to the class Anthozoa. They have a jellyfish-like larval stage that settles onto a rock and permanently anchors there. Adults have a single opening for the digestive system, which is surrounded by a fringe of often colourful tentacles. These are lined with stinging cells called nematocysts that harpoon tiny plankton. Reef-building corals also have symbiotic algae within their bodies that help them to secrete the protective calcium carbonate skeletons which make up this biodiverse habitat.

TAPEWORMS

Phylum: Platyhelminthes

Phylum also includes:
Flukes, flatworms

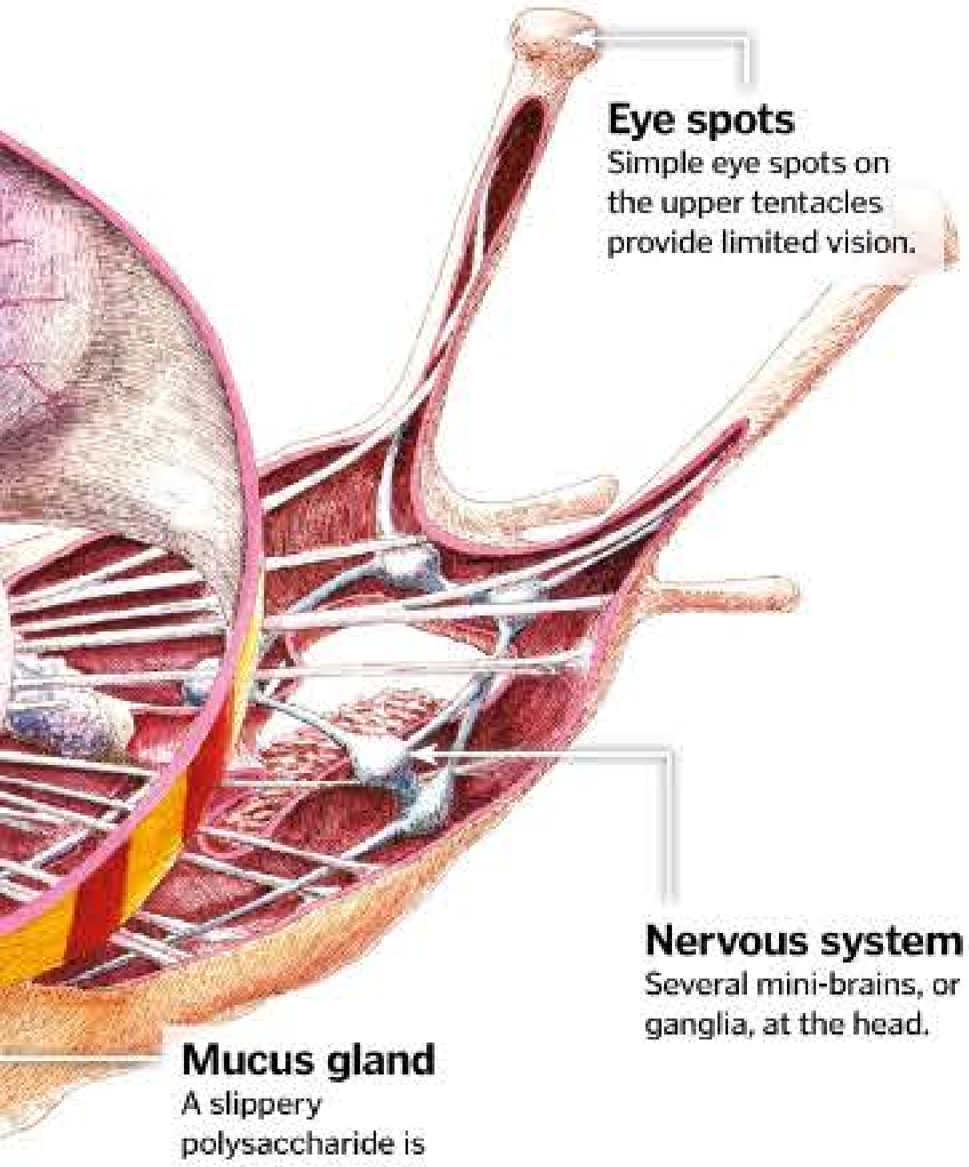
Info: The Cestoda, or tapeworms, are intestinal parasites of vertebrates. They have absolutely no digestive system and are hermaphroditic. They absorb nutrients from their host and reproduce by detaching the egg-filled tail segments into the host's faeces.

CLITELLATA

Phylum: Annelida

Phylum also includes:
Lugworms, ragworms

Info: The Clitellata is the class that includes the common earthworm. They have segmented bodies with internal dividing walls. The gut, circulatory and nervous system run the length of the worm, but other organs are repeated in each of the body segments.



Eye spots
Simple eye spots on the upper tentacles provide limited vision.

Nervous system
Several mini-brains, or ganglia, at the head.

Mucus gland
A slippery polysaccharide is secreted under the snail as it moves.

> "Allopatric speciation occurs when animals are geographically isolated"

the same species are those that can interbreed to produce healthy offspring. You can cross a lion and a tiger to produce a liger, but this hybrid animal is almost always sterile, because lions and tigers belong to different species (Panthera leo and P tigris, respectively).

Charles Darwin's crucial insight was to see that new species arose when an existing population split into two groups that stopped breeding with each other. This can happen in two main ways. Allopatric speciation occurs when animals are geographically isolated. The islands of the Galápagos archipelago, for example, are just close enough together to allow birds to fly between them – when blown off course by a severe storm, for instance – but far enough apart to prevent the populations of two islands from routinely interbreeding.

Over time, the random shuffling of genes from generation to generation, as well as natural selection caused by the different conditions on each island, leads the populations to evolve in completely different directions. Darwin found that each isle had its own unique species of mockingbird. An ancestral species of mockingbird had split into four new species. Similarly, the chimpanzee and bonobo species formed when the Congo River divided the population of ancestral apes in half, around 2 million years ago.

The opposite of allopatric speciation is sympatric speciation. This is where a species splits into two distinct forms that don't interbreed, even though they still share the same territory. An example of this happening today is the American apple maggot fly (Rhagoletis pomonella). Despite its name, the larvae of this species originally fed on hawthorn berries. When the apple was introduced to America around 200 years ago, a few flies must have laid their eggs on apples instead. Female flies normally choose to lay their eggs on the same fruit as they grew up in, and male flies generally mate with females near to the fruit that they grew up in. This means that even though the two populations of flies could theoretically interbreed, in practice they do not.

In the last two centuries, some genetic differences between the two populations have emerged and eventually R pomonella could

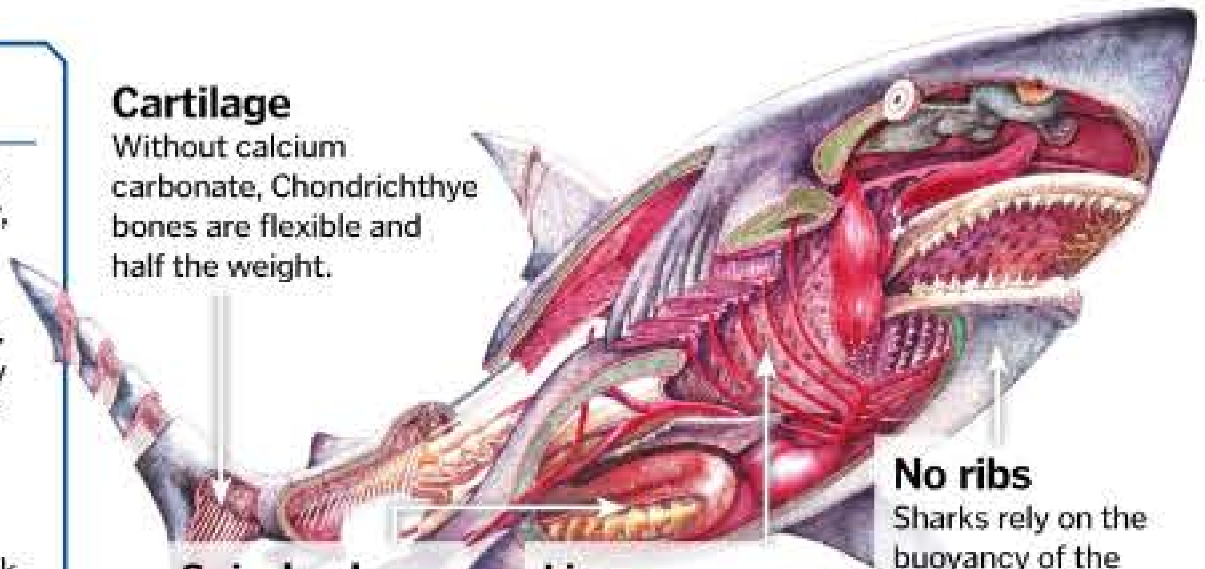
Vertebrate biology

Discover what characteristics are shared by creatures with a backbone

FISH

Phylum: Chordata

Info: Most fish belong to the class Actinopterygii, which are the bony, ray-finned fishes. The other main class of fish contains the sharks, rays and skate, or Chondrichthyes. The two groups aren't actually any more closely related to each other than, say, birds and reptiles. The bony fishes have a calcified skeleton, swim bladder and large scales on the skin. Sharks may look externally quite similar to bony fish, however their body structure is quite different, as we see here.



Cartilage
Without calcium carbonate, Chondrichthye bones are flexible and half the weight.

Spiral valve
Increases the surface area to compensate for the short intestine.

Liver
Contains squalene oil to maintain buoyancy instead of a swim bladder.

No ribs
Sharks rely on the buoyancy of the water to support their bodies.

REPTILES

Phylum: Chordata

Info: Reptiles are air-breathing vertebrates that lay their eggs on land, though some actually live in water. They have scaly skin, and modern reptiles are cold-blooded, although some large prehistoric ones may have been warm-blooded. Reptiles are a leftover category; rather than having defining features of their own, they are classified as the vertebrates that produce eggs with an amniotic sac that aren't mammals or birds.

AMPHIBIANS

Phylum: Chordata

Info: Amphibians were the first vertebrates to emerge onto the land. They still lay their eggs into water and most have an aquatic larval stage. The adults have air-breathing lungs but can also breathe underwater through their skin. They are cold-blooded and need to keep their skin moist. Amphibians have tiny teeth or none at all, but often have a large muscular tongue that can be used to catch prey.

Pain in the class

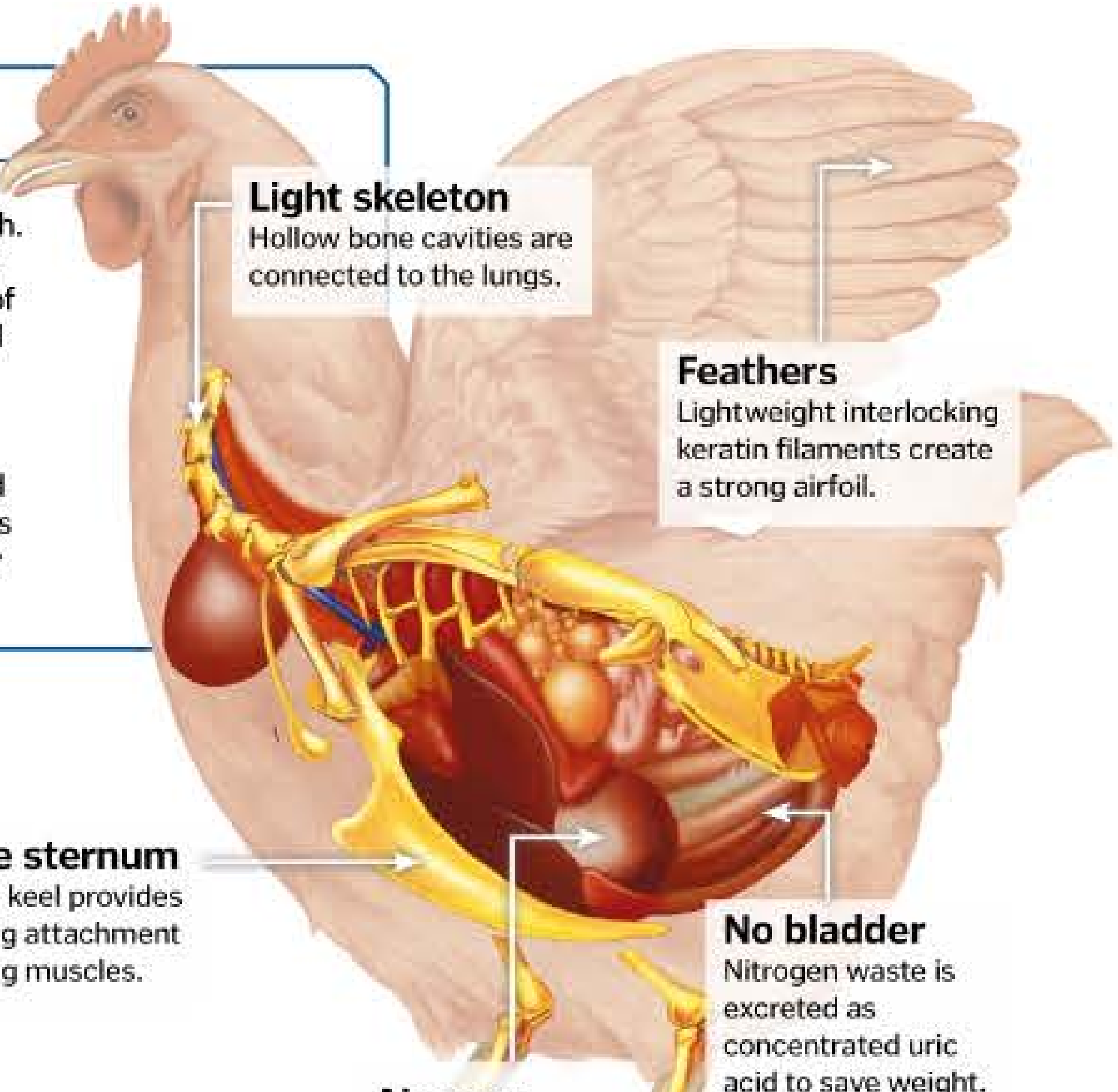
The duck-billed platypus lays eggs, but also has a bill and webbed feet. It also has mammary glands and fur. Is it a bird or a mammal? It's actually a monotreme, once treated as a separate group on the same level as mammals. Nowadays taxonomists class them as a subgroup of mammals. Another problem animal is Peripatus, which looks like a caterpillar but actually has more in common with an earthworm. Its evolutionary journey has got stuck halfway between the annelids and arthropods, which makes it hard to know which group to put it in. The lungfish are a similar halfway house between the bony fish and the amphibians. Worst are the microscopic Myxozoa that have variously been classed as protozoa, worms and jellyfish – though they actually look nothing like any of them!

DID YOU KNOW? *Disney's Animal Kingdom park in Florida is home to over 1,700 animals across 250 different species*

BIRDS

Phylum: Chordata

Info: Birds are vertebrates with feathers and a beak instead of teeth. They lay eggs with a hard, calcified shell, instead of the leathery shell of reptile eggs. Most birds can fly and almost all their characteristic features are adaptations for flight. Their breathing system involves a complicated system of air sacs and chambers in their bones that allows them to refill their lungs when they breathe out as well as in.



Light skeleton
Hollow bone cavities are connected to the lungs.

Feathers
Lightweight interlocking keratin filaments create a strong airfoil.

Large sternum
A deep keel provides a strong attachment for wing muscles.

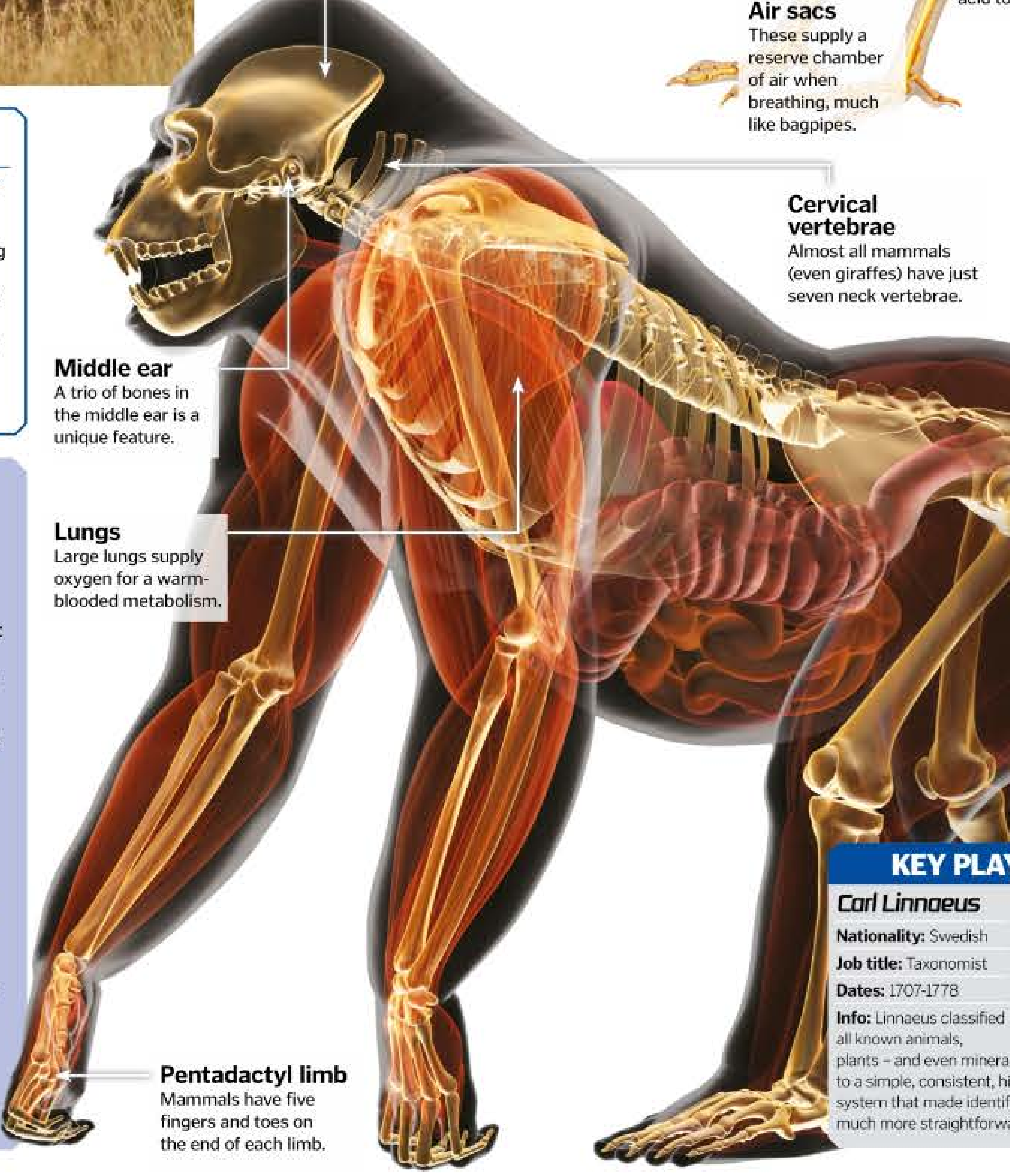
No bladder
Nitrogen waste is excreted as concentrated uric acid to save weight.

Air sacs
These supply a reserve chamber of air when breathing, much like bagpipes.

MAMMALS

Phylum: Chordata

Info: Mammals are defined by their body hair and their mammary glands for feeding young. Most mammals nourish the embryo using a placenta that grows out of the uterus. Monotremes are a primitive group of mammals that comprise the platypus and echidnas; they lay eggs, but even then the egg develops for a long time inside the mother and is nourished by her.



Neocortex
Mammalian brains have a unique system of folds, called the neocortex.

Cervical vertebrae
Almost all mammals (even giraffes) have just seven neck vertebrae.

Middle ear
A trio of bones in the middle ear is a unique feature.

Lungs
Large lungs supply oxygen for a warm-blooded metabolism.

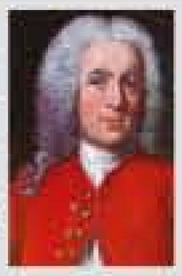
Pentadactyl limb
Mammals have five fingers and toes on the end of each limb.

A molecular family tree

A good classification system doesn't just group animals that *look* similar; it groups those that are related evolutionarily. The best way to do this is by comparing their DNA. All animal cells contain organelles called mitochondria and these have their own DNA. Assuming that mitochondrial DNA only changes as a result of random mutation, the amount of mutation over evolutionary time can be used to create a family tree. Molecular phylogenetics is the scientific discipline that compares the mitochondrial DNA barcode of different animals, and groups the most similar ones together. It is certainly not a perfect system though because it has to make some assumptions about the background mutation rate, and we now know that mitochondria can also acquire new DNA from other sources by horizontal gene transfer.

KEY PLAYER

Carl Linnaeus



Nationality: Swedish

Job title: Taxonomist

Dates: 1707-1778

Info: Linnaeus classified all known animals, plants – and even minerals – according to a simple, consistent, hierarchical system that made identification much more straightforward.

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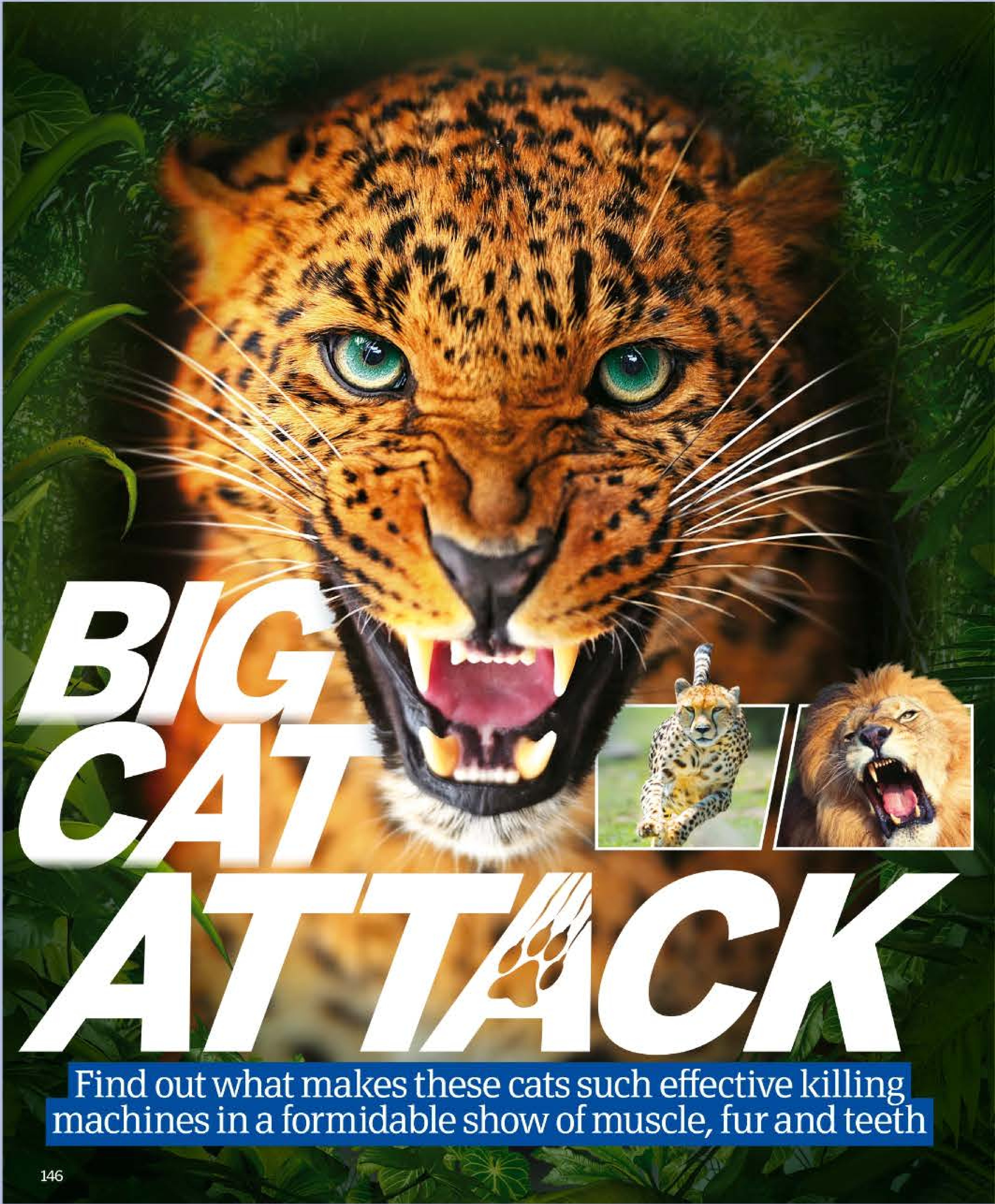


BIG CAT ATTACK

Find out what makes these cats such effective killing machines in a formidable show of muscle, fur and teeth

DID YOU KNOW? *The name 'jaguar' is from the Native American word 'yaguar' meaning 'he who kills with one leap'*

The world's big cats are majestic powerhouses of muscle and strength, with acute senses and killer instincts. The true big cats are the four largest species of the genus 'Panthera': lions, tigers, jaguars and leopards. However, there are also many other large cat species that have incredible hunting abilities, one of which is the mighty cheetah.

Mostly found in sub-Saharan Africa, cheetahs are super-streamlined and built for killing on the fly. They have specialised muscle fibres to power their long limbs, black 'tear lines' to help counteract glare from the African sun and a spotted coat to keep them camouflaged in the long grasses.

Although their spots may look similar at first glance, a closer look reveals that leopards (which often share the cheetah's habitat) have very different markings. Leopard spots are more detailed, featuring clusters of black and brown rosettes rather than the cheetah's simple black ovals. These markings mimic the shifting shadows of trees and leaves, allowing the cheetah to blend into the background. If one's stalking you, you won't know about it until it's too late! Leopards have a wider range, and can be found in forests, deserts, mountains and grasslands throughout Africa and Asia.

> "Lions can even take down the largest animals on land: elephants"

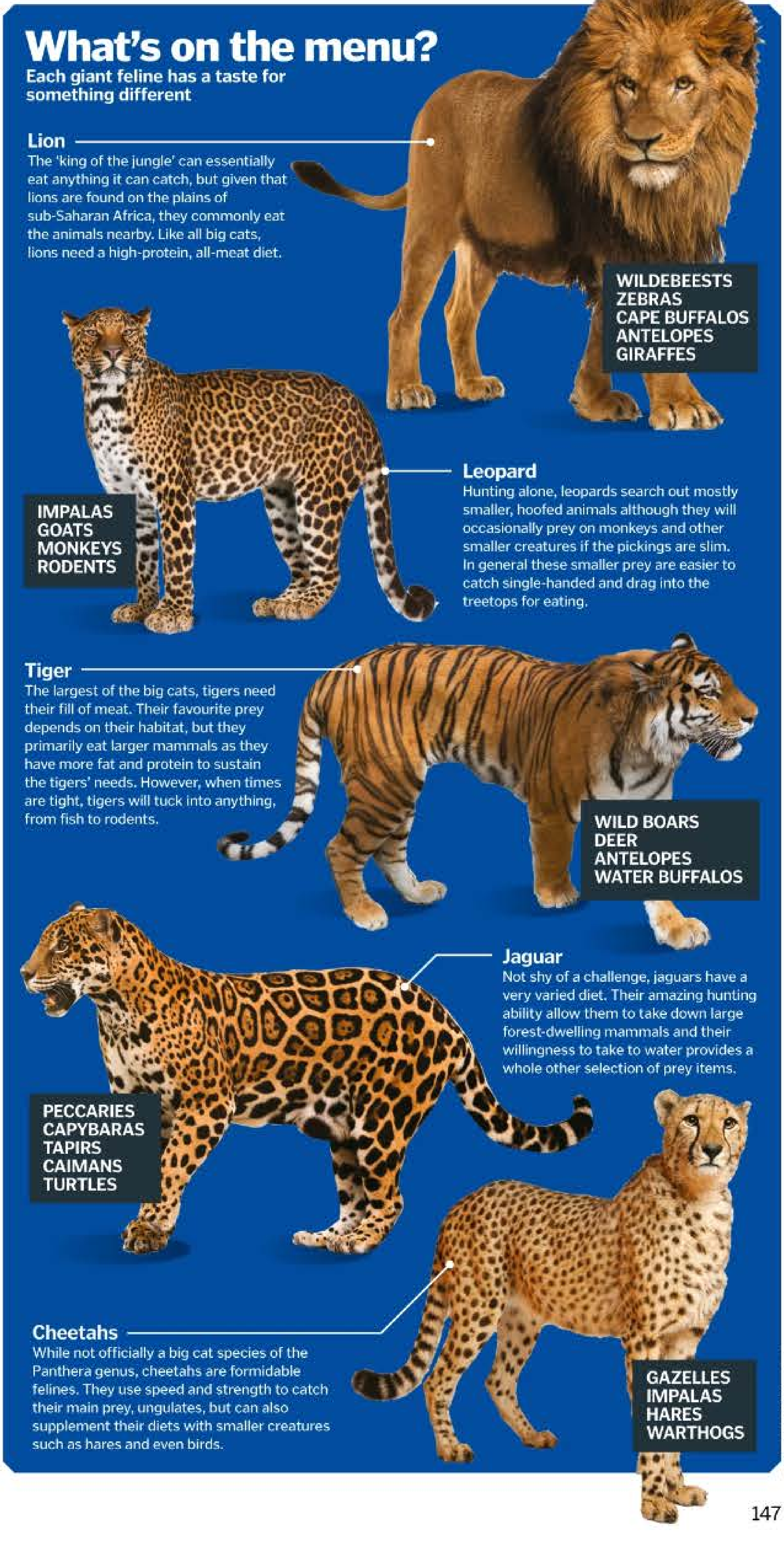
Back on the savannah, it's the lions that have the edge. When they're feeling really plucky, these cats can even take down the largest animals on land: elephants. They can do this because they have evolved to work together. Hunting as a group allows lions to take on much larger animals, surrounding and overwhelming them. It's thought that this ability to hunt cooperatively is due to a highly developed frontal cortex – the part of the brain that deals with problem solving and social behaviour. This is particularly evident in lionesses, the pride members that do the majority of the hunting. These amazing creatures stake a claim to be the most intelligent of the big cats. Competition is vast, though.

As the largest of the big cats, tigers are supreme predators. Found in swamps, grasslands and rainforests throughout Southeast Asia, China and the mountains of far-east Russia, these striped heavyweights hunt alone, relying on their camouflage and stealth to track down prey and catch it with the element of surprise.

Read on to get under the skin of all of these fierce felines, and find out more about the physiology of a big cat attack.

What's on the menu?

Each giant feline has a taste for something different



Lion
The 'king of the jungle' can essentially eat anything it can catch, but given that lions are found on the plains of sub-Saharan Africa, they commonly eat the animals nearby. Like all big cats, lions need a high-protein, all-meat diet.

Leopard
Hunting alone, leopards search out mostly smaller, hoofed animals although they will occasionally prey on monkeys and other smaller creatures if the pickings are slim. In general these smaller prey are easier to catch single-handed and drag into the treetops for eating.

Tiger
The largest of the big cats, tigers need their fill of meat. Their favourite prey depends on their habitat, but they primarily eat larger mammals as they have more fat and protein to sustain the tigers' needs. However, when times are tight, tigers will tuck into anything, from fish to rodents.

Jaguar
Not shy of a challenge, jaguars have a very varied diet. Their amazing hunting ability allow them to take down large forest-dwelling mammals and their willingness to take to water provides a whole other selection of prey items.

Cheetahs
While not officially a big cat species of the Panthera genus, cheetahs are formidable felines. They use speed and strength to catch their main prey, ungulates, but can also supplement their diets with smaller creatures such as hares and even birds.

© Thinkstock; Shutterstock

The need for speed

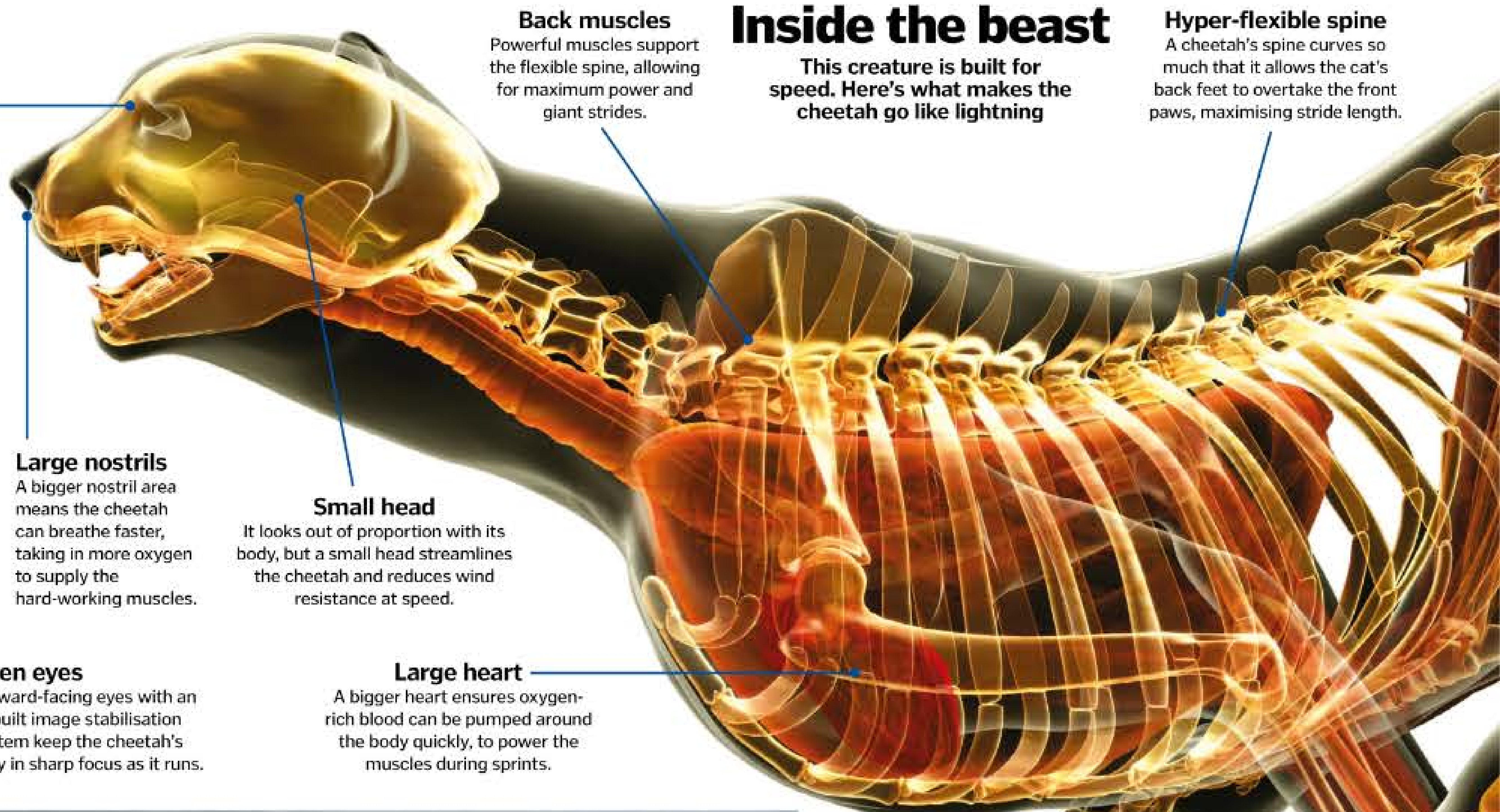
For some big cats, speed is the name of the game

Have you ever looked at a picture of the African savannah, and seen lions walking among a group of impalas and wondered why the impalas are just grazing away, instead of running for their lives? This is because the impalas know that a single lion in the open isn't fast enough and they can easily outrun them. The lions know this too, and won't waste their energy trying. For other big cats though, speed is everything. Leopards use speed for a quick-fire burst, usually after they have expertly stalked their prey and got within striking distance. Similarly, tigers use a swift leap or lunge to grab their prey once it's within reach. The element of surprise is key!

Cheetahs are the real athletes of the big cats, though. They can sprint for long distances and accelerate quickly, with some records clocking up a sustained distance of around four kilometres and an acceleration of 0 to 75 kilometres per hour in two seconds. However, they can only stay at their top speed for around 400 to 800 metres, so they must plan their attack carefully. They will approach downwind from the prey so that their scent doesn't give them away, and then launch an ambush at lightning speed. If they time this well, they will successfully outpace their prey and go in for the kill.

Inside the beast

This creature is built for speed. Here's what makes the cheetah go like lightning



Back muscles
Powerful muscles support the flexible spine, allowing for maximum power and giant strides.

Hyper-flexible spine
A cheetah's spine curves so much that it allows the cat's back feet to overtake the front paws, maximising stride length.

Large nostrils
A bigger nostril area means the cheetah can breathe faster, taking in more oxygen to supply the hard-working muscles.

Small head
It looks out of proportion with its body, but a small head streamlines the cheetah and reduces wind resistance at speed.

Keen eyes
Forward-facing eyes with an in-built image stabilisation system keep the cheetah's prey in sharp focus as it runs.

Large heart
A bigger heart ensures oxygen-rich blood can be pumped around the body quickly, to power the muscles during sprints.

Claws and paws
Sturdy pads and non-retracted claws both provide grip and traction when the cheetah begins to pick up speed.

The cheetah's incredibly flexible skeleton allows a huge range of movement, giving it the edge over its prey

A cheetah's dewclaws, or 'thumb' claws, are used to trip up its prey

DID YOU KNOW? *Cheetahs hunt every two to three days. They only have a 60% success rate, and 10% of their kills are stolen!*

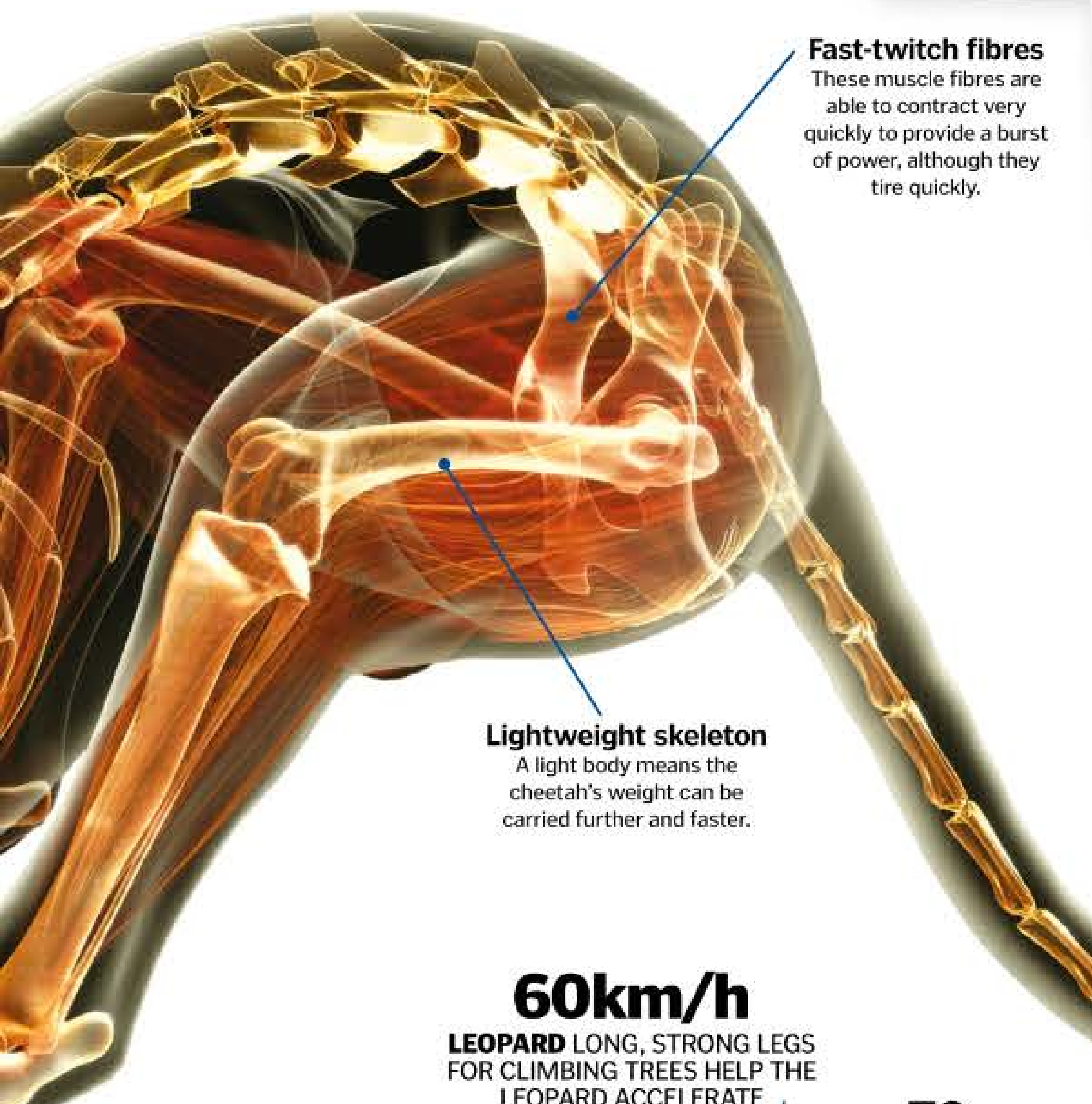
Why cheetahs don't roar

Only the 'true' big cats, those in the genus Panthera (lions, tigers, leopards and jaguars) can let out a deep, guttural roar. This is because the part of their voice box known as the hyoid bone is flexible. Coupled with a stretchable ligament it makes a sound-producing passage and the more the ligament stretches, the deeper the pitch.

Cheetahs, along with other 'smaller' big cats like pumas, instead have a similar voice-box anatomy to house cats. The hyoid bone is completely hardened, meaning roars are impossible to generate. The voice box is a fixed structure, but this allows them to purr – something that the Panthera cats cannot do. Interestingly, the exception to the rule is the snow leopard; although it is a member of the Panthera genus and has a flexible hyoid, this cat can neither roar nor purr! Instead, it makes a 'chuffing' sound.

Cheetahs communicate with other vocalisations instead, like high-pitched chirps and low chuffs

Cheetahs can make tight turns even at high speeds thanks to their long tails



Fast-twitch fibres
These muscle fibres are able to contract very quickly to provide a burst of power, although they tire quickly.

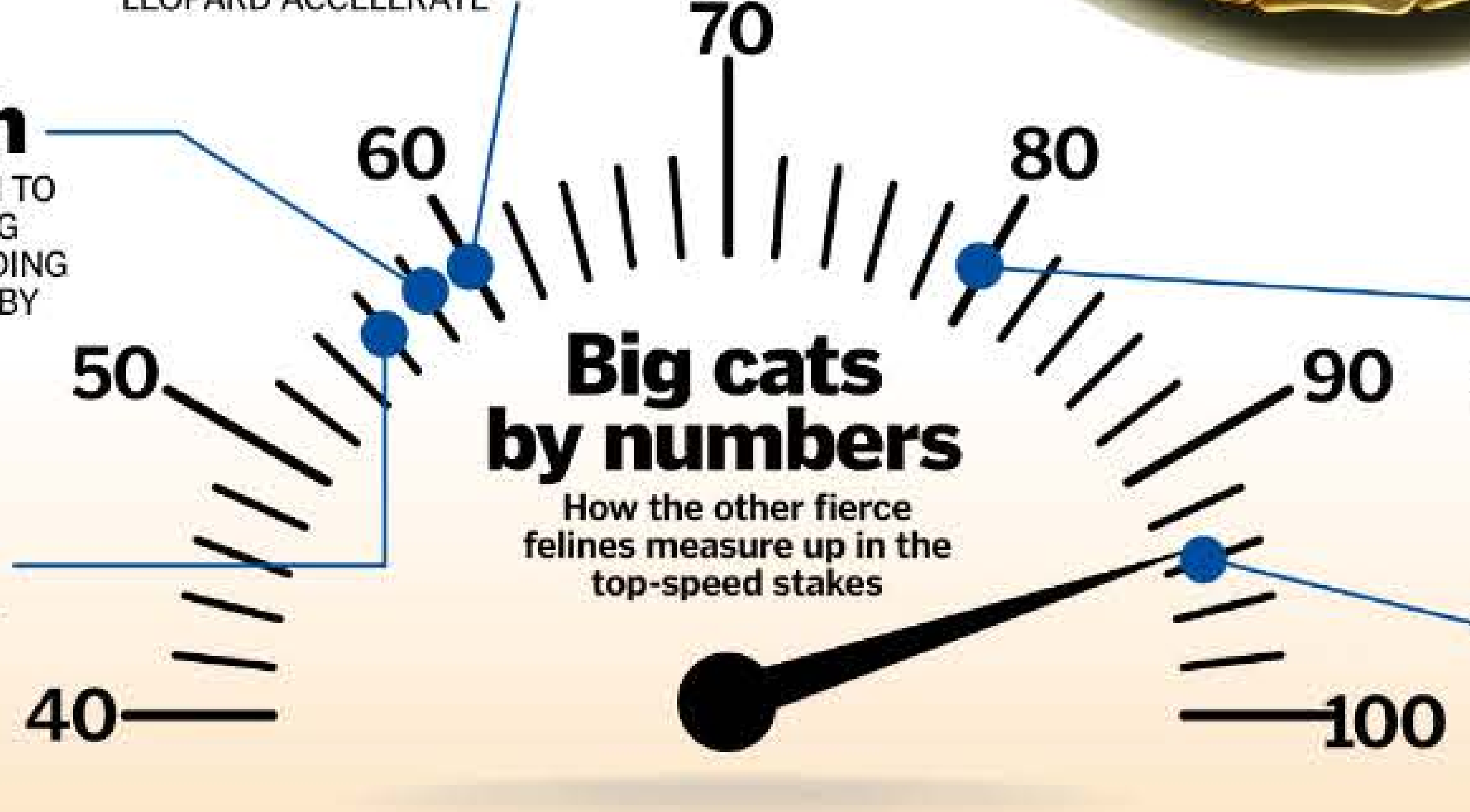
Lightweight skeleton
A light body means the cheetah's weight can be carried further and faster.

Long tail
This acts as a counterbalance and a rudder, helping the cat make tight turns at high speed.

> *"Only 'true' big cats let out a deep, guttural roar"*

Big cats by numbers

How the other fierce felines measure up in the top-speed stakes



60km/h
LEOPARD LONG, STRONG LEGS FOR CLIMBING TREES HELP THE LEOPARD ACCELERATE

59km/h
LION FAST ENOUGH TO CATCH A RUNNING WILDEBEEST, PROVIDING OTHERS ARE NEARBY

56km/h
TIGER THE LARGEST BIG CAT CAN MOVE RAPIDLY IN VERY SHORT BURSTS

80km/h
JAGUAR STILL BEHIND THE MIGHTY CHEETAH, BUT THE FASTEST OF THE REST

94km/h
CHEETAH FASTEST ANIMAL ON LAND

© FLPA; Getty; Thinkstock

Strategy of the hunt

Each predator plays to its strengths, executing different tactics to hunt and catch their prey

Lions use their sheer size, brute strength and power in numbers to go after large prey items, such as buffalos, zebras and giraffes. They both stalk prey and attack en masse, coming at prey from different angles to startle and confuse. Lions will also scavenge, stealing kills off other predators such as hyenas and cheetahs.

All the other big cat species are solitary hunters, and need to employ a very different and more fine-tuned approach. Cheetahs use their highly specialised bodies to generate massive thrust, using propulsion and attuned senses to home in on their quarry. They then use their dewclaw to trip the prey, causing it to stumble and fall.

Tigers will use their keen senses and superb camouflage to stay hidden in the undergrowth. They stalk prey until close enough to strike – lunging at it from around six metres away. With razor sharp claws outstretched, any animal in this cat's sights may struggle to get away! These cats can even launch attacks from water. The tiger will then use its bulk to grapple with its prey.

Snow leopards are ambush predators and will use their rocky, mountainous home to their advantage. They will often creep up on prey near cliff ledges and drop onto them from above.

Leopards and jaguars have similar strategies. To locate prey in the dark, leopards have excellent night vision, around seven times better than ours. They rely on their hypersensitive paws to feel the terrain, ensuring that no twig-snaps or leaf rustles give away their position. A quick lunge and a powerful bite are enough to seal the deal. However, due to their climbing preferences, these cats will employ the 'drop from above' tactic too. Leopards and jaguars aren't afraid of swimming and will happily get wet to secure a meal, or sometimes they won't bother hunting at all, and will keenly scavenge a meal.

Life in the pride

Each member of the pride has its own role, to ensure all the lions benefit from family life

Lionesses do the majority of the hunting for the pride

Young males
When they reach maturity, young males are often ousted and leave the pride to form bachelor groups before they join their own pride.

Lionesses
There are around 12 lionesses in a pride unit, and they are usually all related.

Time to leave
If a male or female is injured or too old and can't perform their role, they are pushed out of the pride.

Safety in numbers
Lions live in open grasslands, where a kill draws easy attention. The pride works together to defend food from scavengers.

Mealtime hierarchy
After a kill, the males always eat first. Then the females will eat their fill and the cubs follow.

> *"Big cats' finely tuned senses make them hyper-aware of their surroundings"*

Hunting school

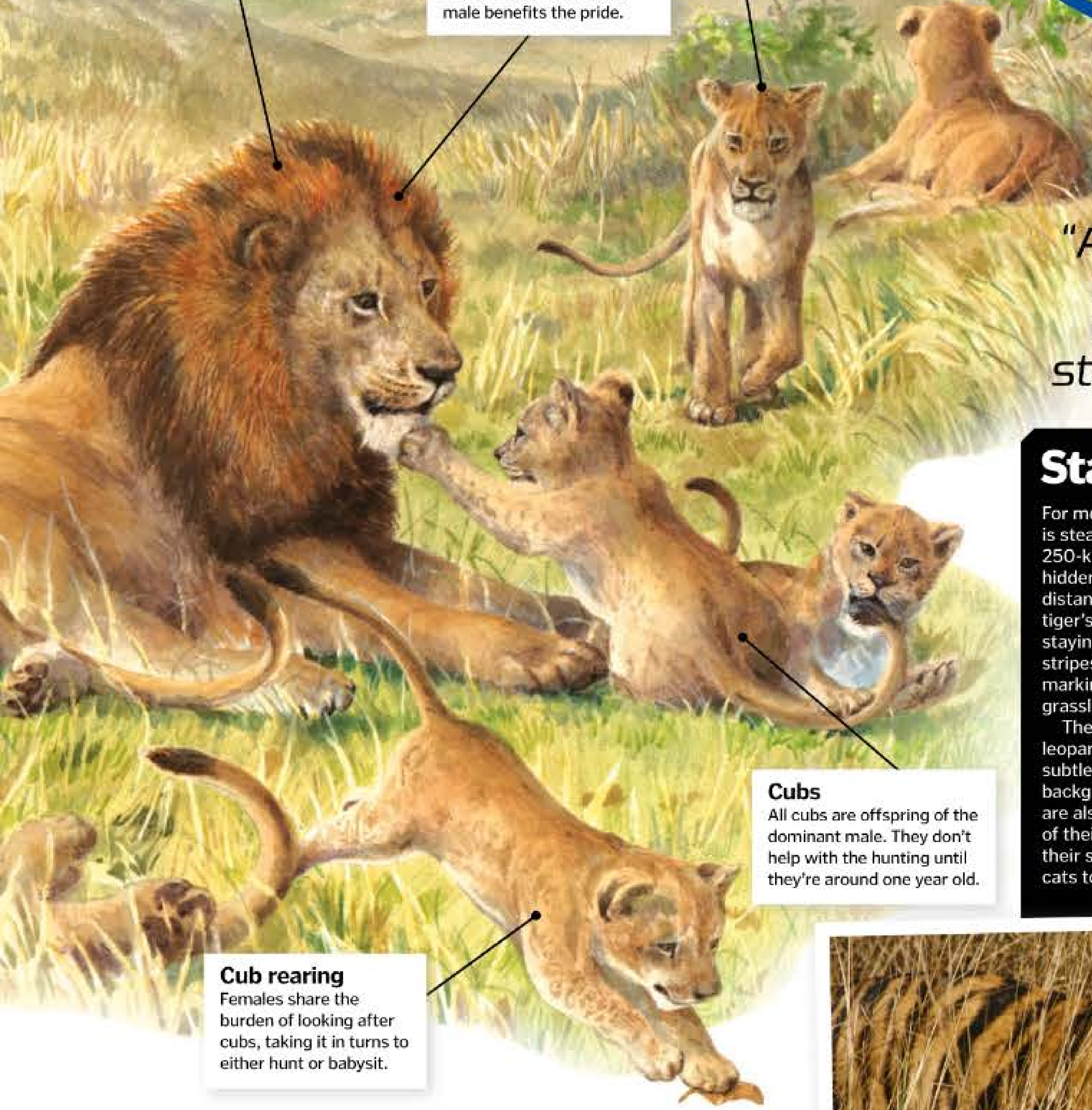
Lesson number one: eat, or be eaten! How young cubs learn to be predators

Lion
Play fighting is a big part of learning. Lions in the pride will encourage cubs to pounce and stalk one another before being introduced to live prey.

Tiger
By the time they reach 18 months, tiger cubs will be skilled hunters. They learn through watching their mother and finishing off her contests.

Leopard
The essential skills that leopard mothers teach their young include how to pin down animals, and the best place to clamp down on a throat.

DID YOU KNOW? *Leopards are strong climbers and can drag their prey up into the trees to eat*



Dominant male
The male guards the territory, chasing away intruders and would-be adversaries to protect his lionesses.

Male challengers
The dominant lion may be challenged for his females and territory, so a strong male benefits the pride.

Cooperative hunting
Females work together to bring down a kill, making hunting both efficient and effective.

Cubs
All cubs are offspring of the dominant male. They don't help with the hunting until they're around one year old.

Cub rearing
Females share the burden of looking after cubs, taking it in turns to either hunt or babysit.

Teamwork is key; lions can bring down much larger prey because they work together

> *"A group of lions will come at prey from different angles to startle and confuse"*

Staying stealthy

For most big cats, their most powerful weapon is stealth. But how does a two-metre-long, 250-kilogram Bengal tiger manage to stay hidden long enough to get within striking distance of its prey? The answer lies in the tiger's amazing agility, striped camouflage, and staying downwind of the prey. Orange and black stripes may seem garish to us, but these markings break up the tiger's outline in both grassland and jungle.

The same is true for the other big cats – leopards, jaguars and even lions all have subtle markings that blend them into the background. The big cats' finely tuned senses are also essential, making them hyper-aware of their surroundings. This, coupled with their strong and flexible bodies, allow the big cats to hide, waiting for the moment to strike.

© Alamy; Thinkstock

A striped coat helps tigers blend into the undergrowth

Jaguar
Young jaguars stay with their mothers for two years or more. They watch her every move and learn to hunt by her example.

Cheetah
A mother cheetah will teach her cubs to hunt by bringing young or weak prey back to their lair. The cubs can then practise chasing and catching.

In for the kill

After the take-down comes the dispatch, a grizzly yet necessary part of the hunt

When big cats get a hold on their prey and they have paws on the prize, the next step is crucial: the kill. Almost all of the big cats use the method of asphyxiation to kill their prey. This is the quickest method to make sure that the prey does not get away, and that all of the energy these animals have expended on stalking and chasing doesn't go to waste. Big cats have incredibly strong jaws, powered by efficient musculature in their head and neck. To complement a strong jaw are sets of super-sharp teeth, perfect for piercing flesh and holding prey down.

For lions, the kill is usually a team effort. Because they often hunt in groups, one lion will frequently assume the role of clamping its colossal jaws around a prey animal's snout, attempting to suffocate it while the rest of the hunting team hang on its flanks to bring it to the ground. This is sometimes called the 'lion kiss of death', and they can bring down very large prey in this way.

It's very often thought that big cats automatically 'go for the jugular' to dispatch their prey, but this isn't the case. When their teeth aim for the neck, it's the animal's windpipe that the cat is aiming for, rather than the veins. Their vice-like jaws clamp onto the windpipe and crush it, suffocating the prey for a quick kill.

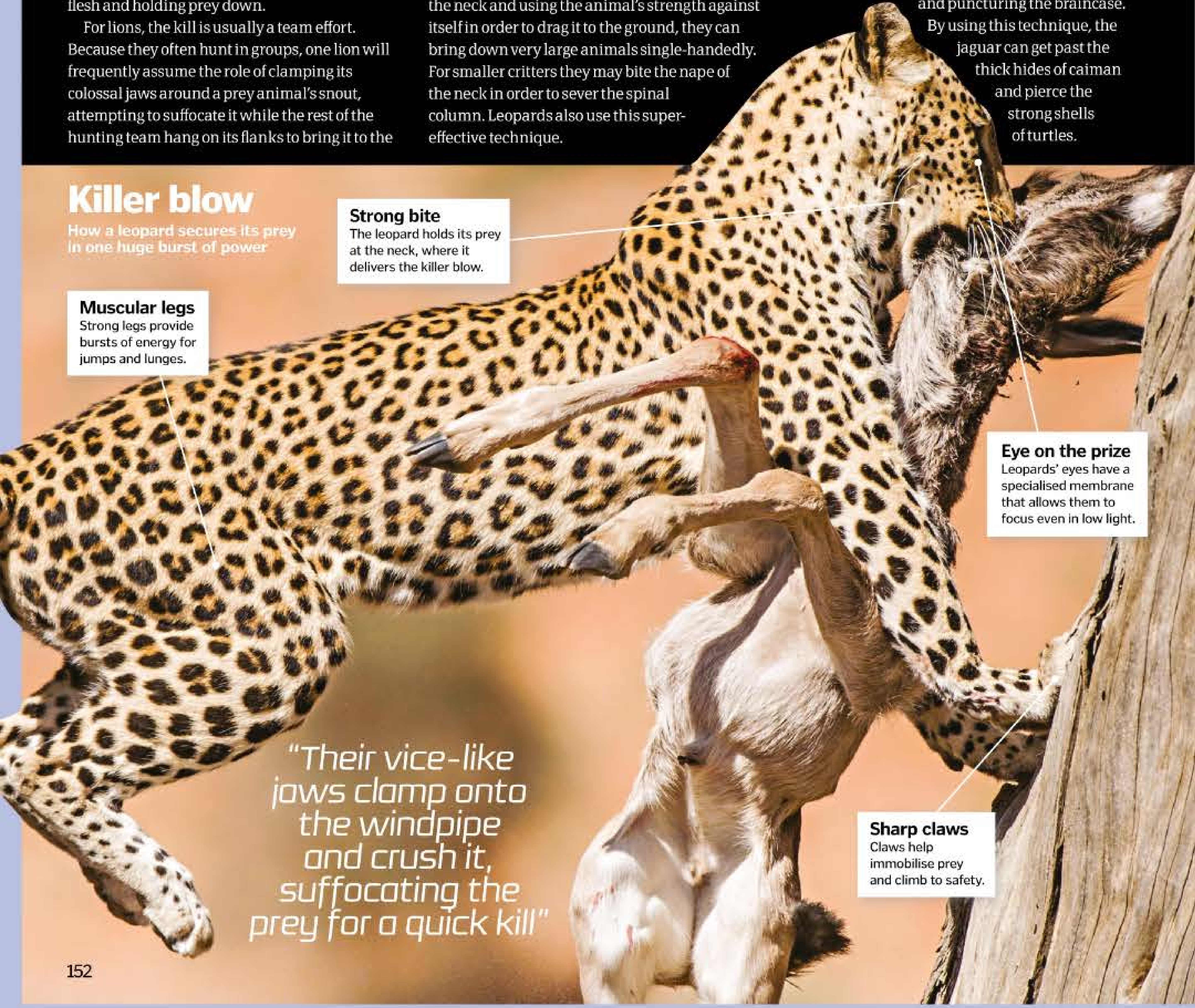
Tigers use this method for larger prey. By biting the neck and using the animal's strength against itself in order to drag it to the ground, they can bring down very large animals single-handedly. For smaller critters they may bite the nape of the neck in order to sever the spinal column. Leopards also use this super-effective technique.

Jaguars, on the other hand, do things a little differently; these animals are the only big cats to prey on reptiles, and it's thought that their killing style has evolved to take down dangerous and armoured prey. The jaguar, instead of going for the throat, directly bites its prey in the back of the neck or head, severing the spinal cord and puncturing the braincase. By using this technique, the jaguar can get past the thick hides of caiman and pierce the strong shells of turtles.

Tigers use their strong front legs to tackle and immobilise their prey, before biting down on the neck

Killer blow

How a leopard secures its prey in one huge burst of power



Strong bite
The leopard holds its prey at the neck, where it delivers the killer blow.

Muscular legs
Strong legs provide bursts of energy for jumps and lunges.

Eye on the prize
Leopards' eyes have a specialised membrane that allows them to focus even in low light.

Sharp claws
Claws help immobilise prey and climb to safety.

> "Their vice-like jaws clamp onto the windpipe and crush it, suffocating the prey for a quick kill"

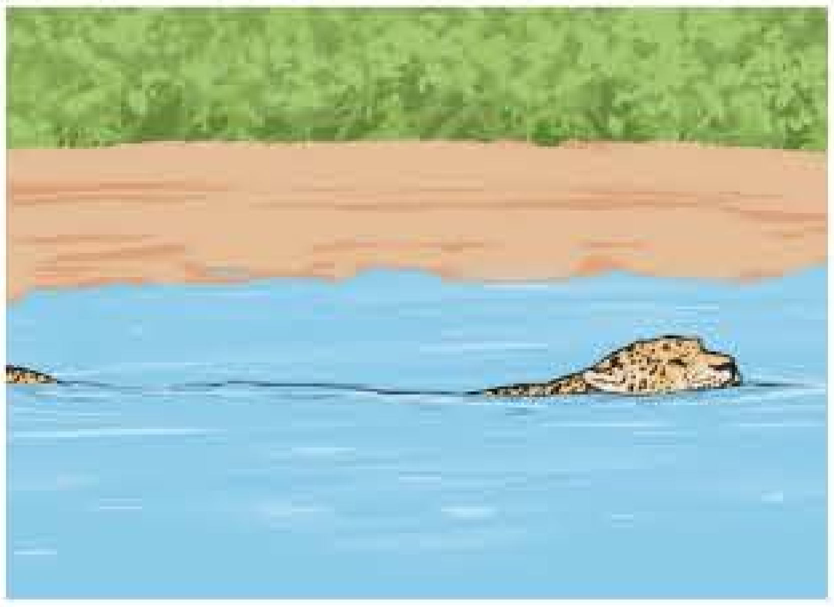
DID YOU KNOW? *Some leopards and jaguars have black fur, and are called 'panthers', but this term is used for any black big cat*

Big cats aren't just restricted to land in order in hunt down some dinner

Working together means the pride can tackle much larger animals, with more meat to go around

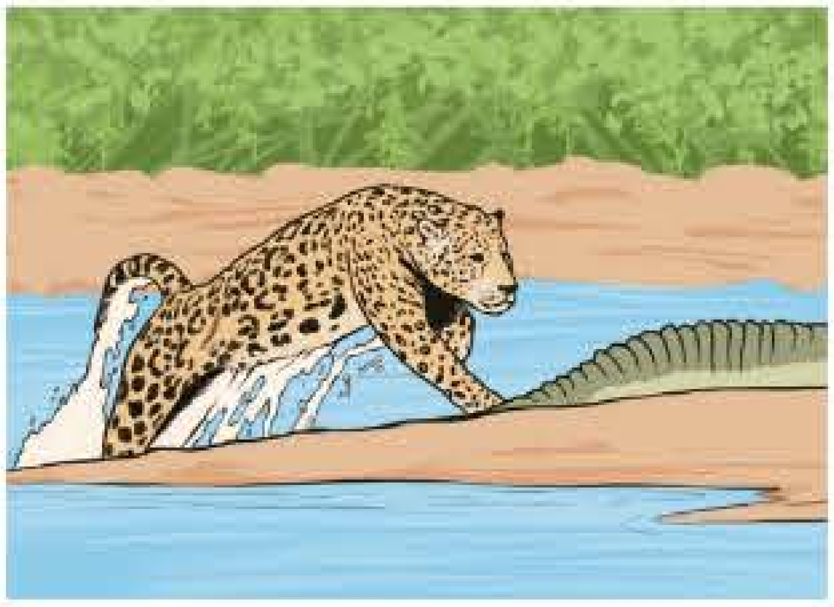
Jaguar vs caiman

These cats aren't scared of water, nor the scaly, snappy reptiles that live within



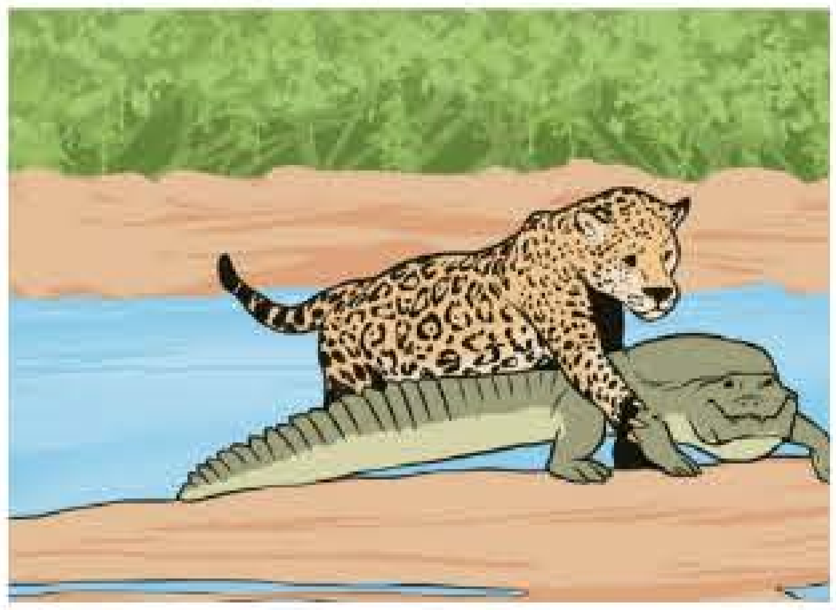
1 The swim

Jaguars are great swimmers. With prey in his sights, this jaguar chooses a water approach, making sure to swim stealthily with no splashes or sudden moves.



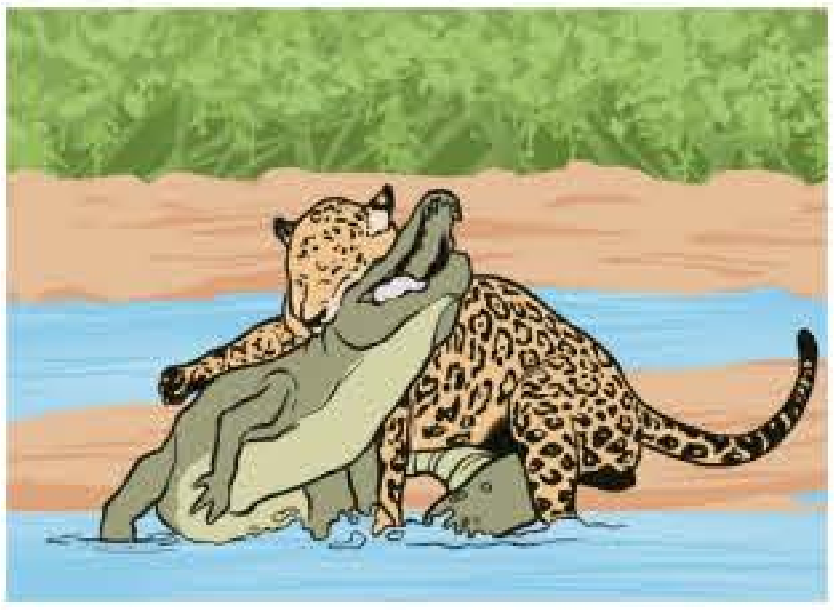
2 The stalk

Exiting the water, the jaguar has the element of surprise on the unsuspecting caiman. He stalks for one second more to get closer.



3 The attack

The caiman has little time to run before the jaguar takes a leap onto him. The jaguar again has the element of surprise and immobilises the caiman.



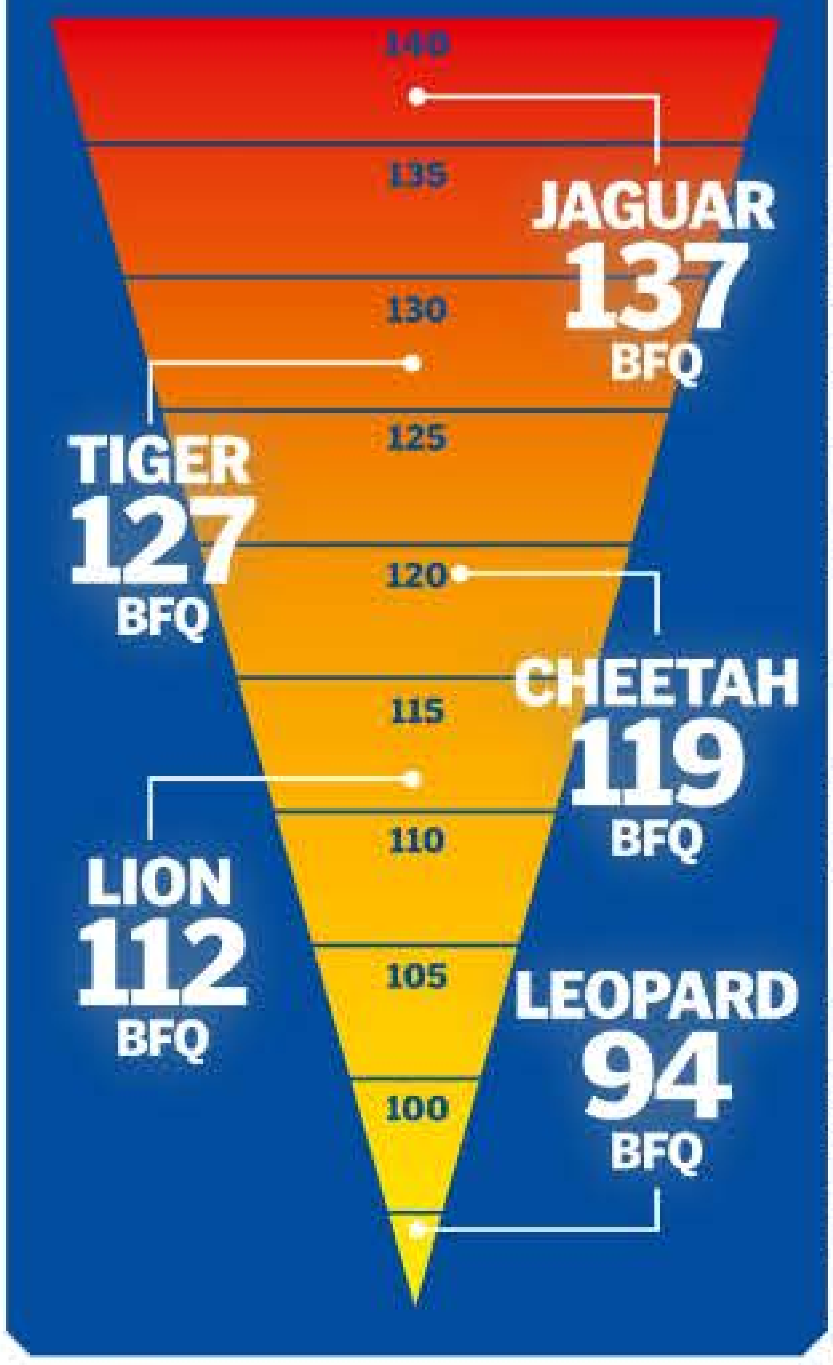
4 The death blow

A sharp bite into the braincase at the back of the caiman's head instantly immobilises the reptile. A successful hunt for the jaguar!

Big cat bite force

Check out the sheer power of these formidable predators

Bite force quotient (BFQ) is a measure of an animal's bite force relative to its body size. For comparison, a domestic cat's BFQ is 58.



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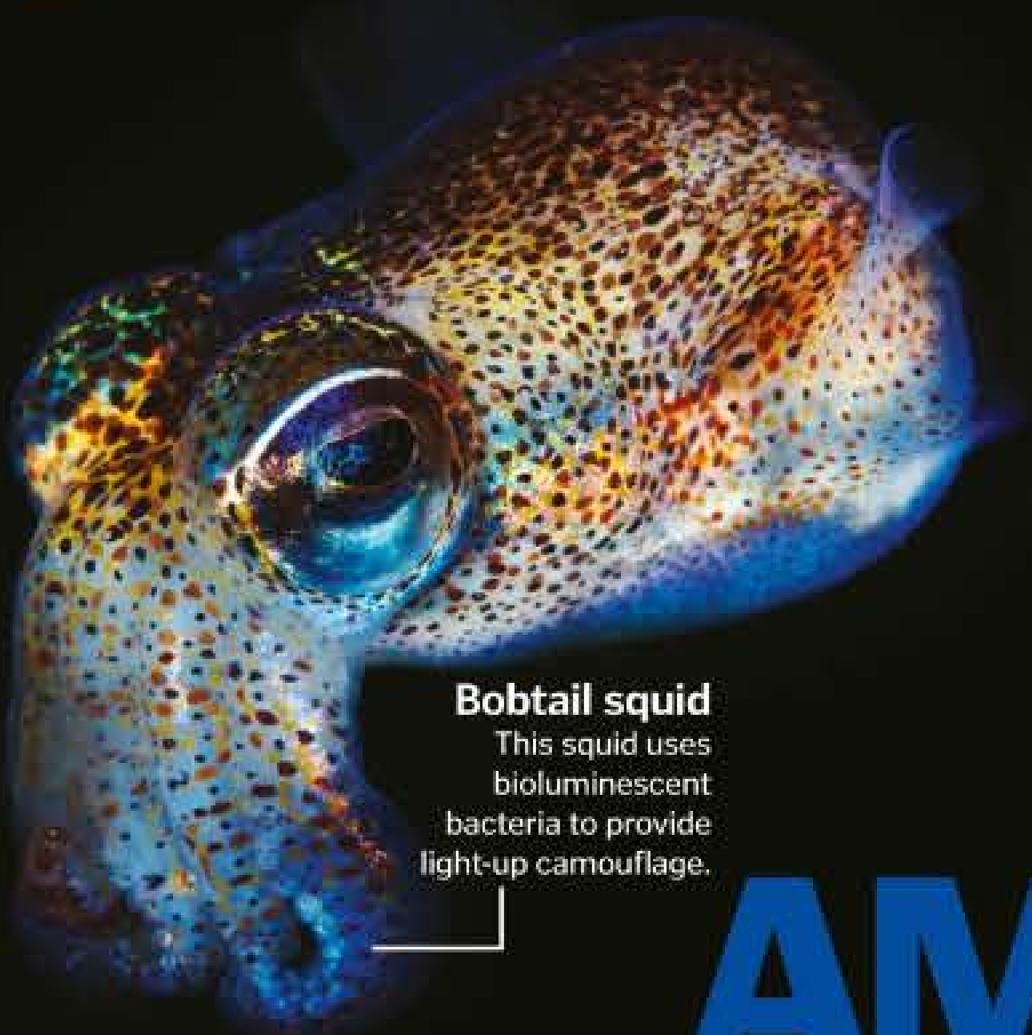


Bobtail squid
This squid uses bioluminescent bacteria to provide light-up camouflage.

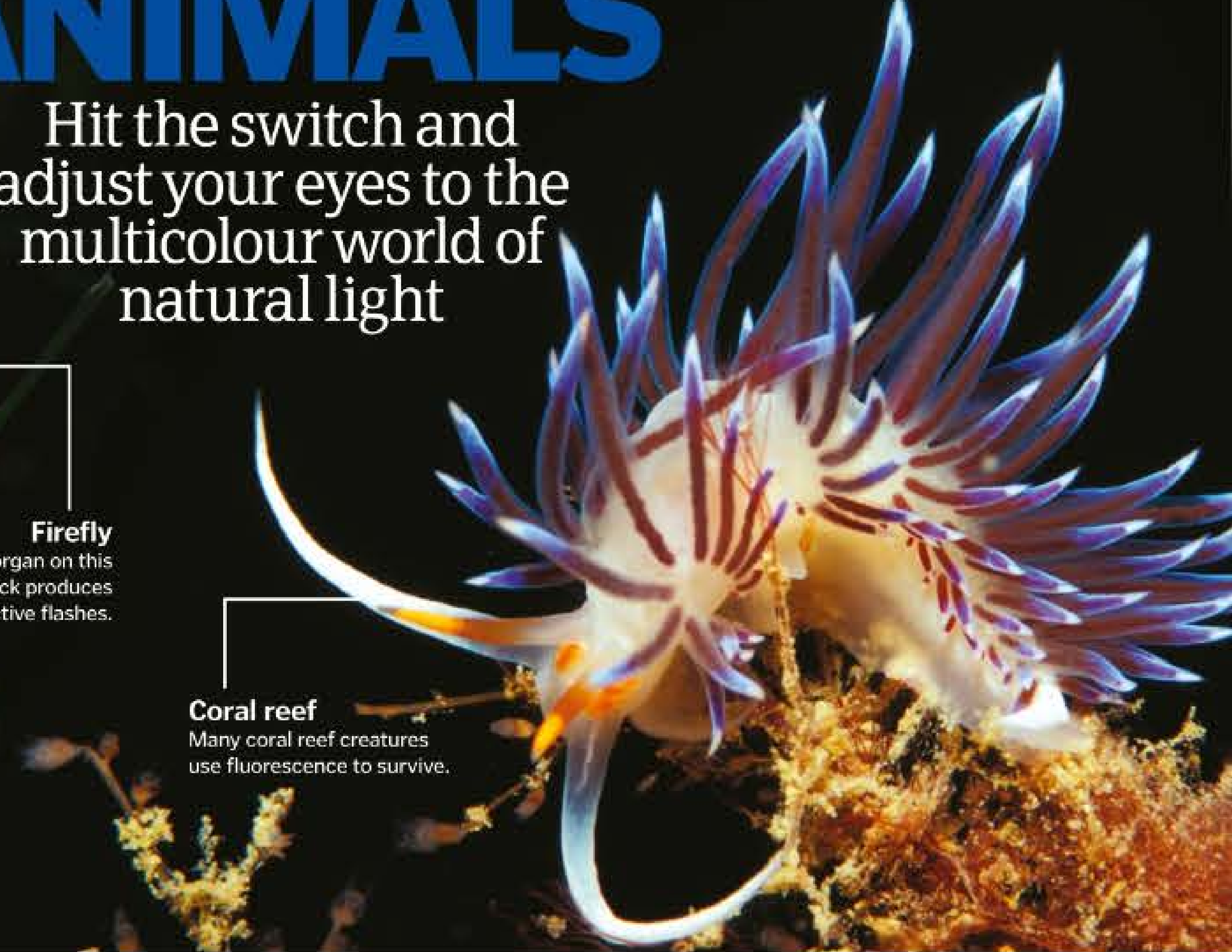
Jellyfish
Some jellyfish species use flashes of light to scare off potential predators.

Scorpion
Scorpions fluoresce under UV light, but no one really knows why.

AMAZING GLOW-IN-THE-DARK ANIMALS

Hit the switch and adjust your eyes to the multicolour world of natural light

Firefly
A light organ on this bug's back produces its distinctive flashes.



Coral reef
Many coral reef creatures use fluorescence to survive.

DID YOU KNOW? *Charles Darwin witnessed bioluminescence onboard the Beagle, noting the "milky train" following the ship*

Imagine walking through a forest at night and encountering a swarm of dancing lights floating in the air. It may look like magic, but it is one of the most astounding features of the natural world: bioluminescence. The flying flickers of light are a biochemical reaction exhibited by tiny fireflies, as they light up the night in their efforts to find a mate.

Bioluminescence is found throughout the animal kingdom and beyond, and the most extensive array of glow-in-the-dark creatures can be found in the ocean. Yet, interestingly, freshwater habitats have almost no bioluminescent organisms.

Although modern science has allowed us to explore the inner workings of how this incredible biology occurs, bioluminescence has been fascinating humans for thousands of years. References to natural creatures glowing in the dark appear in the folklore of many different cultures, in Scandinavia, China and India to name a few. In the fourth century BCE, ancient Greek philosopher Aristotle noted, "some things, though they are not in their nature fire nor any species of fire, yet seem to produce light." Similarly, during the first century CE, Roman scholar Pliny the Elder even documented that he took the slime of a jellyfish from the Bay of Naples and rubbed it on his walking stick, where it lit the way "like a torch."

As Aristotle himself noticed, bioluminescence is a 'cold light', which means that unlike the glow that is produced by electrical light bulbs, which also produces waste heat energy, the bioluminescent reaction is almost 100 per cent efficient and produces very little heat. There are two ways that animals are able to produce this light: by possessing the right biological means to make it themselves, or by hosting bioluminescent bacteria that work with the animal to provide their flashy light show. These bioluminescent bacteria can also be free-living, or parasitic, attaching themselves to a host and making it glow unwittingly.

One animal that has a mutually beneficial relationship with these bacteria is the tiny bobtail squid, a cephalopod just a few centimetres long, found in coastal waters of the Pacific. The squid uses the bacteria's blue-green glow to camouflage itself in the water column by matching the glow of moonlight from above - a technique known as counter illumination. In return, the squid's body provides the bacteria with a sugary solution to feed on. Every morning, the squid will expel 95 per cent of its bioluminescent bacteria, ensuring that it stops glowing while it rests. By the time night returns, the bacteria have repopulated, reaching a large enough concentration to begin glowing again. This is also an interesting use of bioluminescence as camouflage, rather than to light the way in darkness.

Bioluminescent creatures that don't rely on luminous bacteria create their own light via chemical reactions. These animals often have specialist organs called photophores in which organic molecules known as luciferin react with oxygen to produce photons of visible light. These reactions can be initiated by various factors, including chemical, neurological or mechanical triggers.

Bioluminescence is not the only method employed by the animal kingdom to glow in the dark. Many animals also shine through fluorescence, where light is absorbed and then emitted at a different wavelength. For example, under a UV light, scorpions appear a neon turquoise colour. Various species of corals, jellyfish and crustaceans also have fluorescent properties, as does the Japanese eel – which is one of the only known vertebrates to exhibit this trait.

On top of this, animals can also use phosphorescence, which is chemically similar to fluorescence, but the light is absorbed and (unlike fluorescence) still continues to glow once the light source is removed. Many sea creatures will exhibit a combination of the three light-up methods, but phosphorescence is often too weak to see with the naked eye or is overshadowed by the other two, much brighter, methods of natural illumination.

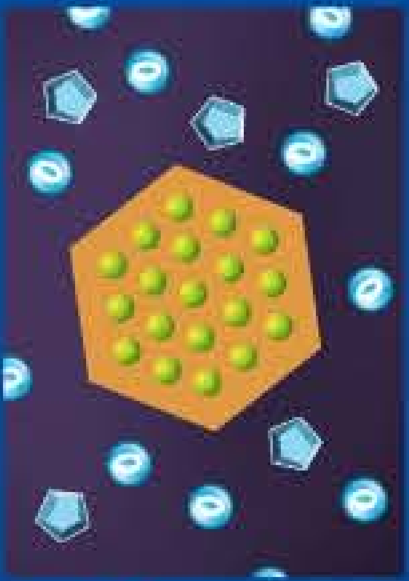
In the ocean, the glowing show of colour very often includes neon hues of blues and greens. This is because these are the wavelengths that travel the furthest in the depths, ensuring that a creature's lights are fit for purpose. However, the colours are also tailored to their specific function. Animals use their glow-in-the dark capabilities for defence, to ward off predators or to dazzle attackers. Lights help to attract both food and mates, and can even provide a cloak of camouflage. It is possible that there are also benefits for the non-luminous ocean beings such as sperm whales, who dive so deep to hunt that scientists believe they may rely on the bioluminescence of their prey in order to track down a meal.

The science behind bioluminescence

Bioluminescence is produced by a chemical reaction involving a molecule known as luciferin

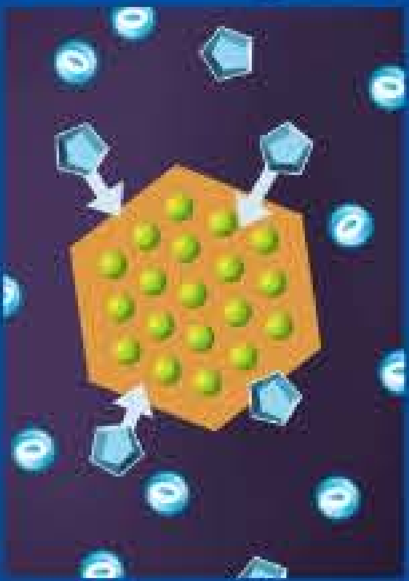
1 Ingredients

In general, for a bioluminescent reaction to occur, an organism needs a luciferin molecule, luciferase (the catalyst which enhances the reaction) and oxygen to oxidise the luciferin.



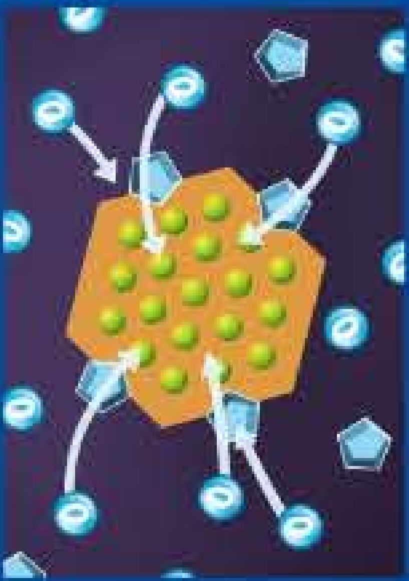
2 Catalyst

A catalyst is a substance that increases the rate of a chemical reaction. In this case, the catalyst is called luciferase. This is the general term for an enzyme that helps a light-emitting reaction to take place.



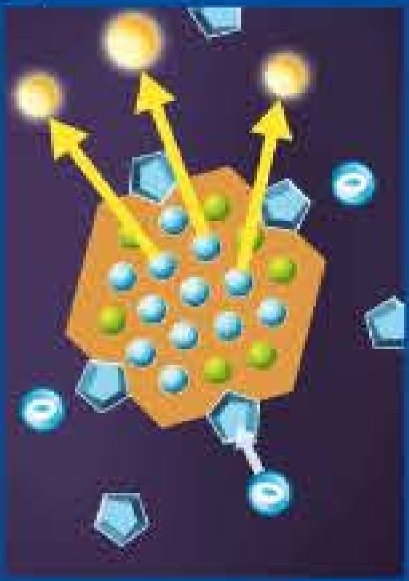
3 Oxidisation occurs

The luciferase provides a pathway for the oxygen so that it can combine with the luciferin more easily. The oxygen then oxidises the luciferin by adding oxygen molecules to it.



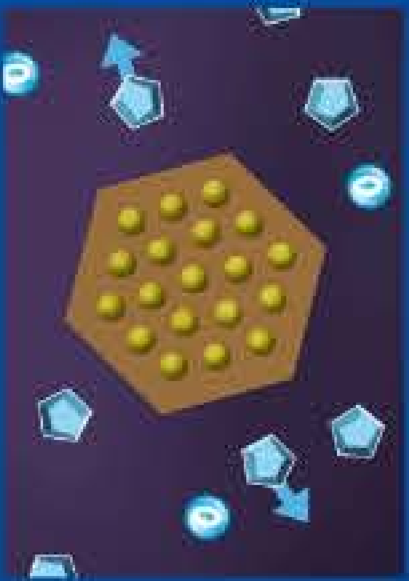
4 Light is produced

When luciferin reacts with oxygen, photons of light are released. When this reaction happens collectively in a creature's photophores, it produces the amazing natural light displays.



5 Reaction by-products

The bioluminescent reaction results in by-products: carbon dioxide and a compound called oxyluciferin – the new name for the oxidised luciferin molecule.



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How natural illumination can benefit us

As a naturally occurring phenomenon, that in its simplest form requires just oxygen to work, bioluminescence can also have many applications in our everyday lives. We can harness this amazing light-emitting process for medical, military and commercial uses. Natural fluorescence, too, is being developed as an increasingly useful tool.

Scientists are able to use naturally fluorescent proteins to track the spread of viruses and diseases in rodents, and also to watch the development of cell tissue in amazing rainbow colours. This has potential for allowing us to understand and treat human disease.

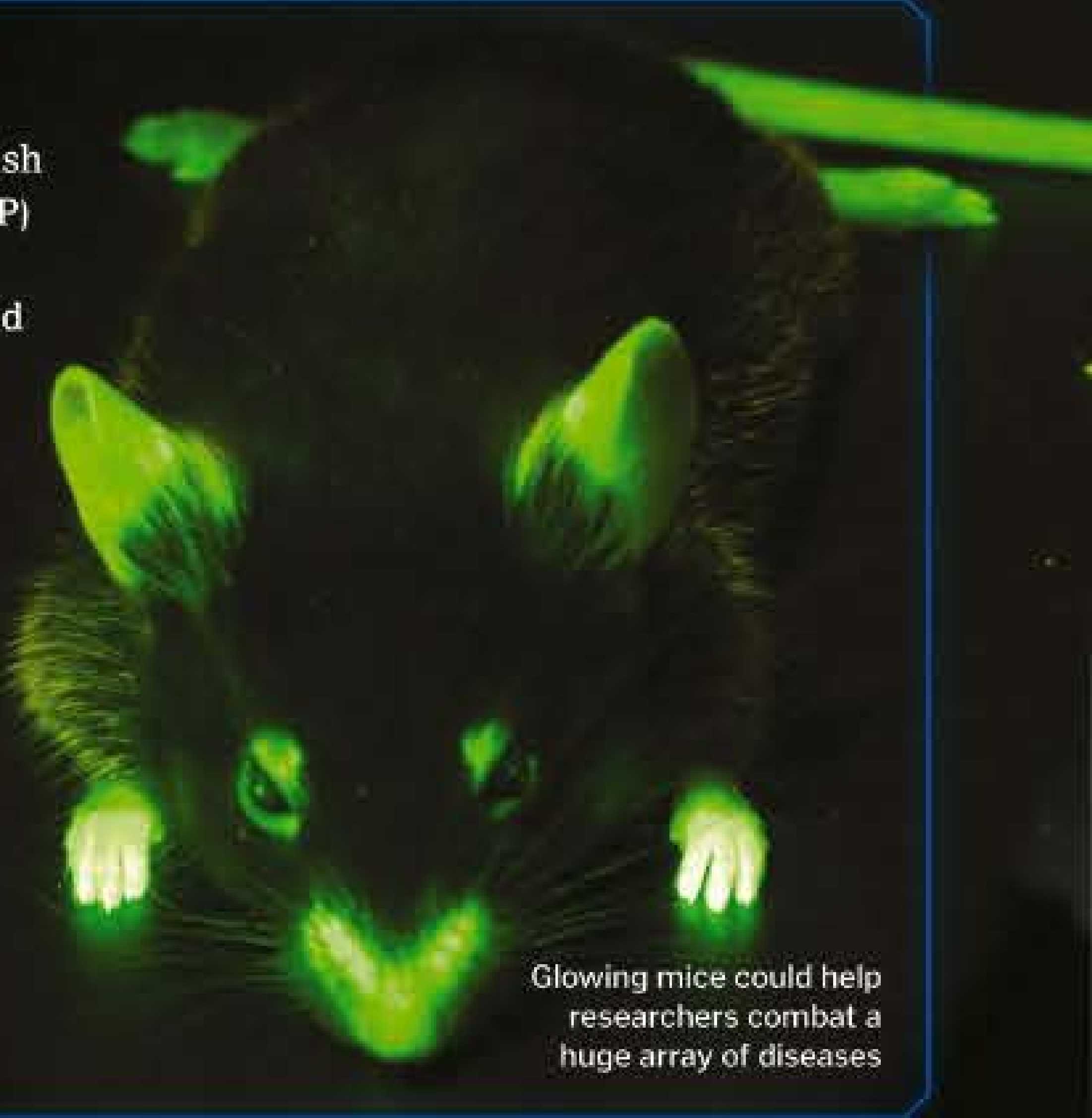
We can also use our knowledge of bioluminescence to genetically modify plants so they glow. Although the science of this is still very much in its infancy, this use of bio-light could go as far as adapting trees to glow in place of streetlights, saving valuable fossil fuels. Scientists at Edinburgh University have already created glowing potatoes that illuminate under a black light when they are dehydrated, working as a marker for farmers to precisely monitor their crops. Although there is controversy surrounding genetically modified foods, the science behind such developments is still incredible.

There might also be military uses for bioluminescence. Certain species of plankton often bioluminesce when they are disturbed, which could give away the whereabouts of otherwise stealthy submarines, or disrupt other covert naval operations.

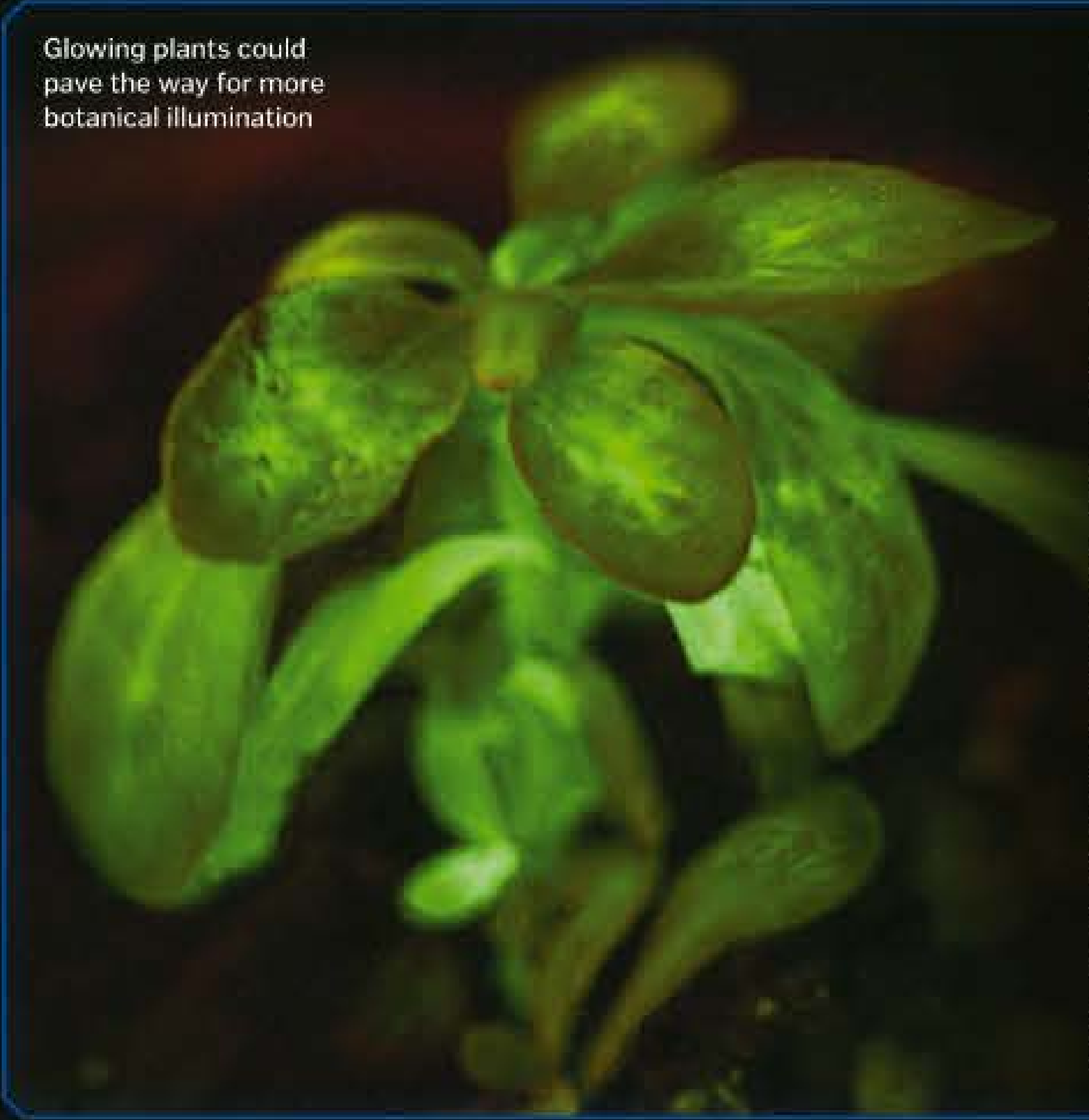
Then there are, of course, plenty of commercial applications to light up our daily lives as well. For example, biotech company BioLume in North Carolina hope to develop a range of incredible luminous sweet treats – such as lollies, chewing gum and drinks – as well as personal care products including toothpastes, soaps and bubble baths that glow in the dark.

Glowing mice

A fluorescent protein derived from jellyfish known as Green Fluorescent Protein (GFP) has revolutionised cell biology. It glows bright green under blue and UV light, and can be used as a versatile marker to highlight a huge array of biological processes. The protein can be cloned (so it doesn't need to be harvested from live jellyfish) and then the gene sequence for GFP can be added to an organism's genome. In turn, this makes specific areas of cells (that scientists want to study) 'glow'. This means scientists are much better able to witness and understand the growth of tissue, from nerve cells in the brain to the spread of cancerous tumours, which has huge potential in medical research.



Glowing mice could help researchers combat a huge array of diseases



Glowing plants could pave the way for more botanical illumination

Glowing greenery

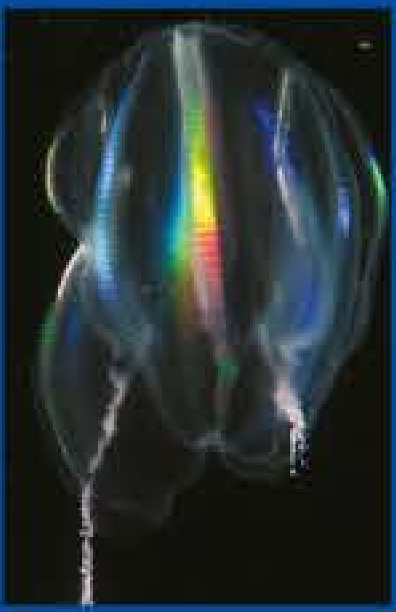
The company Bioglow has been working on an energy-saving alternative to streetlights, by developing a plant that glows on its own. Named Starlight Avatar, a pot plant called Nicotiana alata has had a gene for bioluminescent bacteria inserted into its genome, creating an 'autoluminescent' plant that emits a yellow-green light independently.

Lighting up the deep

Bioluminescence is found throughout the water column, from the surface waters to the deepest ocean trenches. As the light fades, the amount of biological illumination begins to increase. It's thought that around 90 per cent of deep-sea animals use some form of bioluminescent light to hunt, defend themselves and find mates.

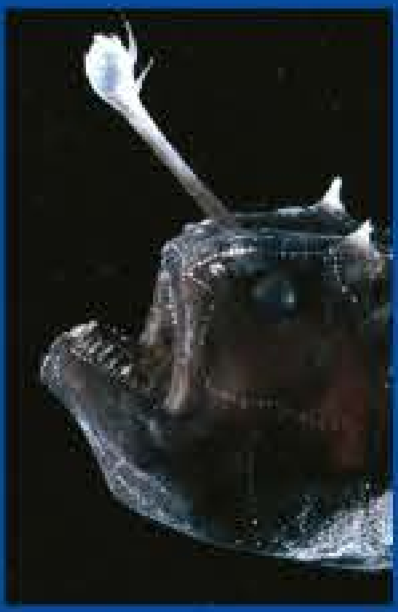
Comb jelly

Despite their name, these tiny organisms are not jellyfish. Comb jellies have paddle-like appendages that propel them, which flash with rainbow light as they move. This happens when incident light is scattered through the moving cilia, but many species are also bioluminescent, capable of glowing blue-green.

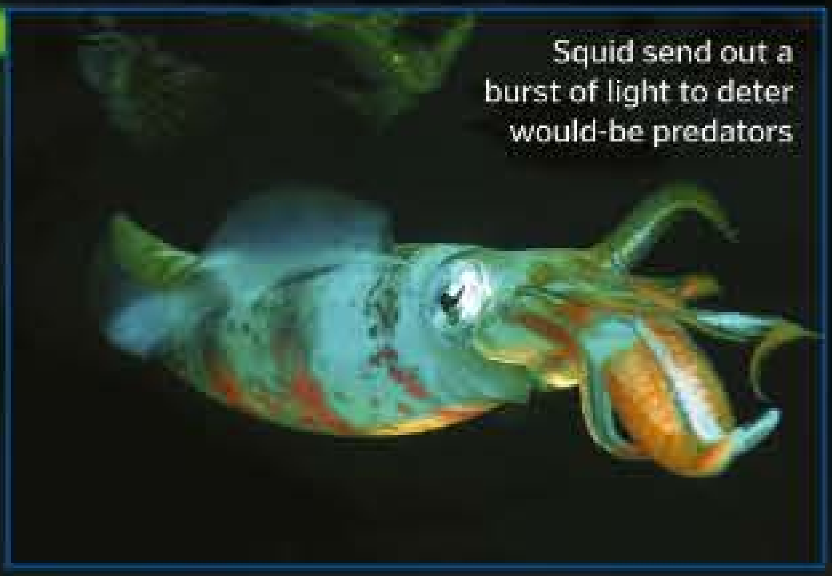


Anglerfish

There are many species of anglerfish, with the majority possessing a large, bioluminescent lure, like a glowing fishing rod. This menacing appendage helps the females to attract prey. Male anglerfish are much smaller and do not have lures, instead they latch on to females like parasites and provide sperm for reproduction.



Why do animals glow?


Squid send out a burst of light to deter would-be predators

Flashlight fish use super-bright light organs beneath their eyes to lure in and illuminate prey

Different firefly species can be identified by their flashing patterns

DEFENCE

Defensive bioluminescence is used to deter predators. Creatures such as squid use a sudden burst of light to startle their attacker, and some animals also employ a 'smoke screen' effect to enable a quick getaway.

OFFENCE

Bioluminescence can be used to attract prey, or to find it by lighting it up. Animals such as some siphonophores and flashlight fish will use their bioluminescence to lure prey towards them, and then enjoy the spoils.

ATTRACTION

Bioluminescence plays a key role in the courtship of fireflies, who have light organs in their lower abdomen. Males perform a light show to attract females, who will flash back in response if they like what they see.

> *"We can harness this amazing light-emitting process for medical, military and commercial uses"*

Black dragonfish

This fearsome looking creature has light-producing cells along its entire length, and it can light up suddenly when disturbed or threatened. However, this fish has an extra trump card: it can glow with near-infrared light, which many other deep sea species are unable to detect, allowing it to launch stealth attacks upon its prey.

Tomopteris

These beautiful-looking creatures are swimming polychaete worms. They have bioluminescent cells that allow them to flash bright colours, and there are species that can even produce yellow light, which is rare in the deep. Tomopteris are also capable of shooting bioluminescent particles that allows them to get away from predators.

Mauve stinger jellyfish

In German, the mauve stinger jellyfish's name translates as 'night light', reflecting its amazing bioluminescent capabilities. When it becomes startled or trapped, the flight response sets off the chemical reaction so it can release a glowing trail of mucous in its wake as it tries to make an escape.

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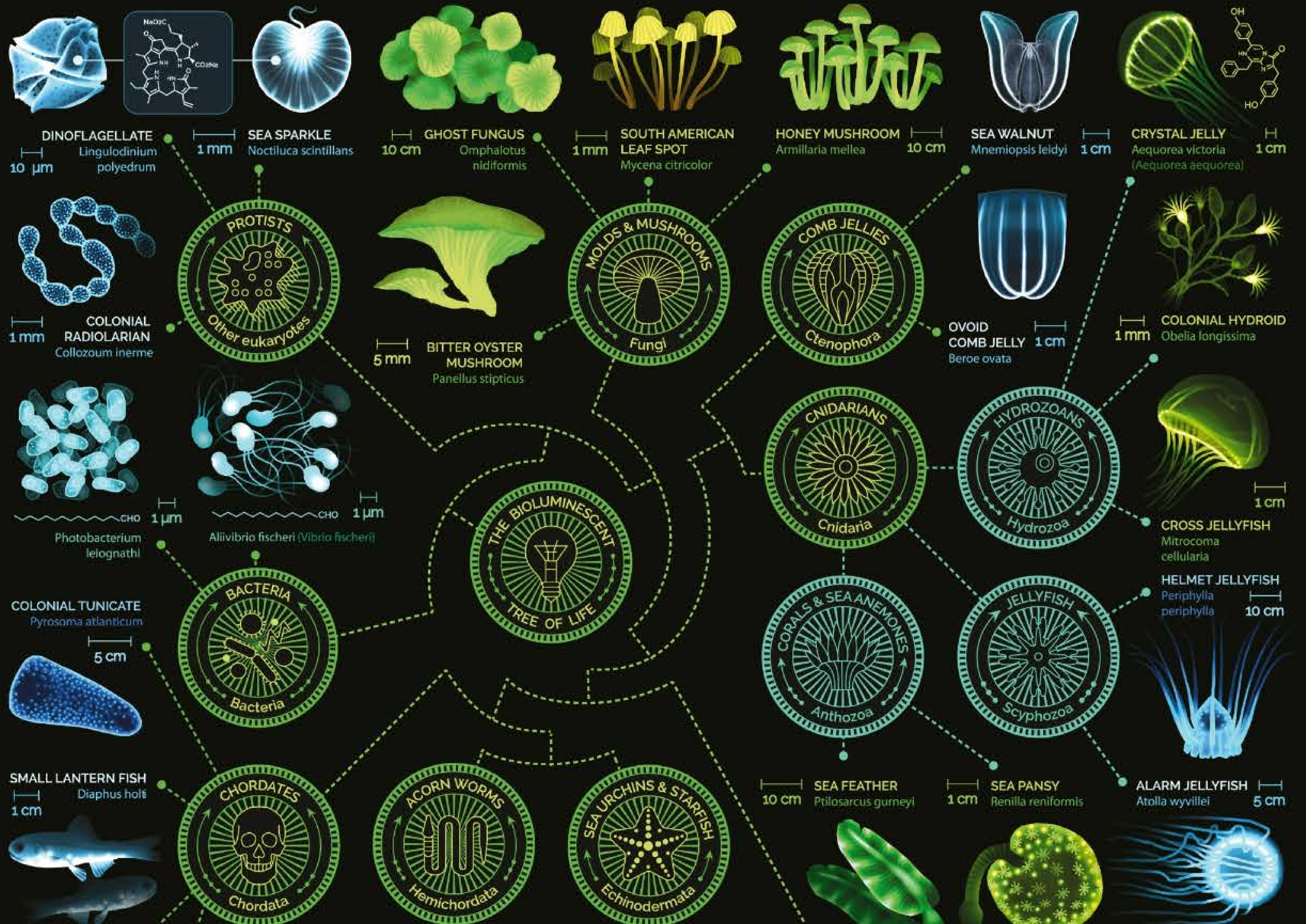
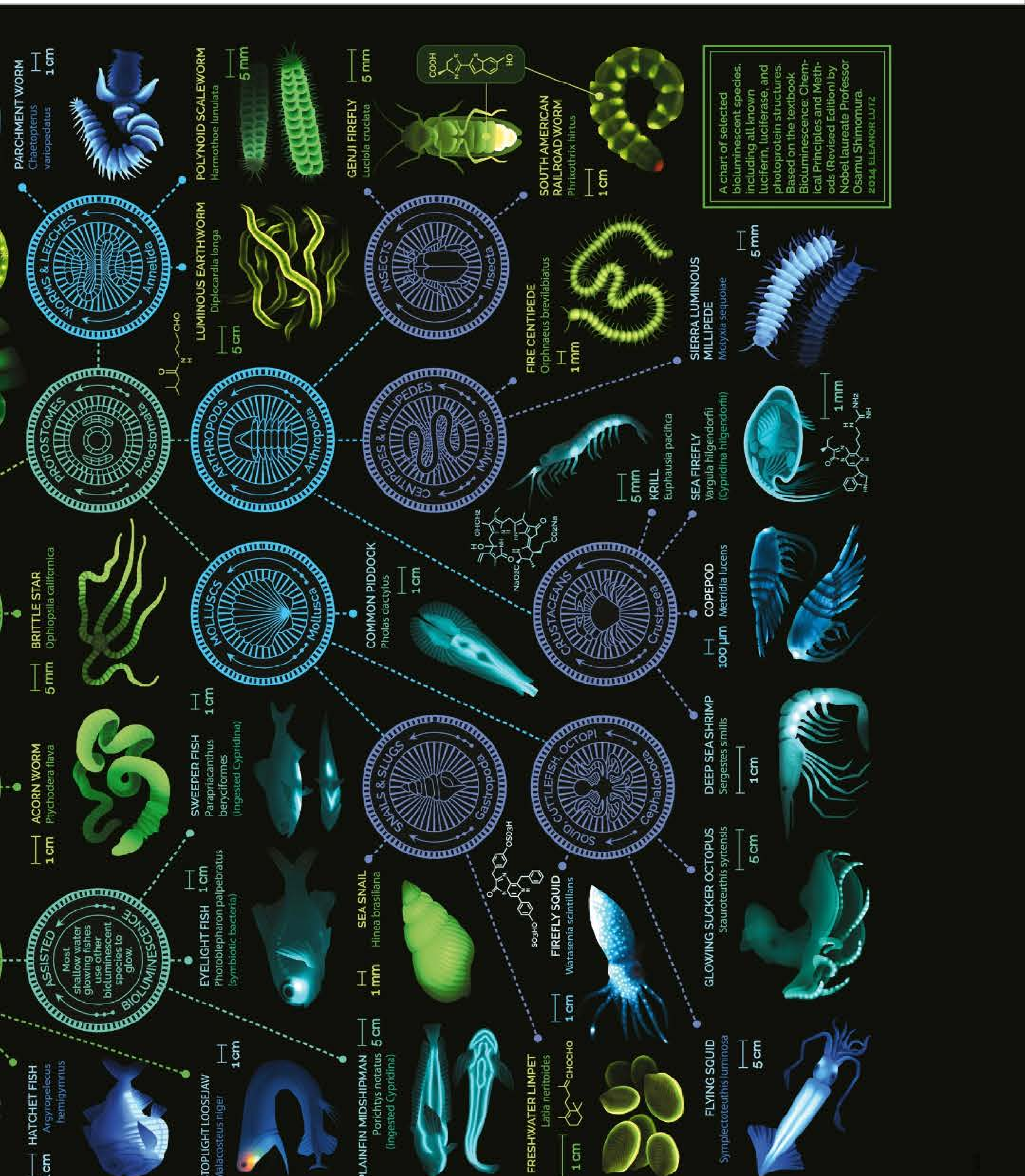
Living lights

The natural world is decorated with an army of organisms using bioluminescence to glow



DID YOU KNOW? *It is thought that bioluminescence could be the most common form of communication on the planet*



A chart of selected bioluminescent species, including all known luciferin, luciferase, and photoprotein structures. Based on the textbook Bioluminescence: Chemical Principles and Methods (Revised Edition) by Nobel laureate Professor Osamu Shimomura.
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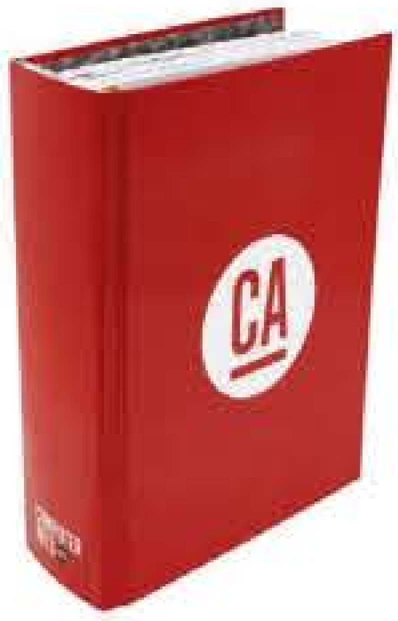

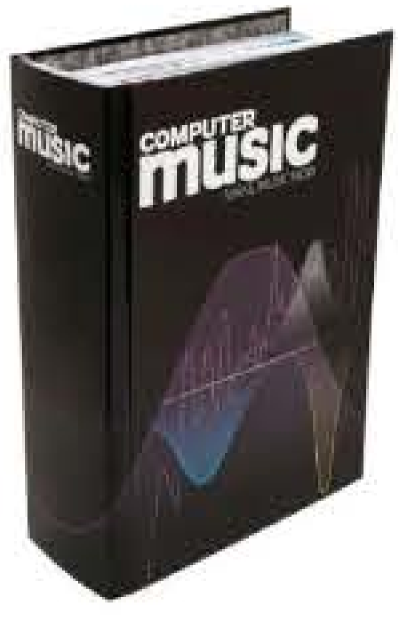

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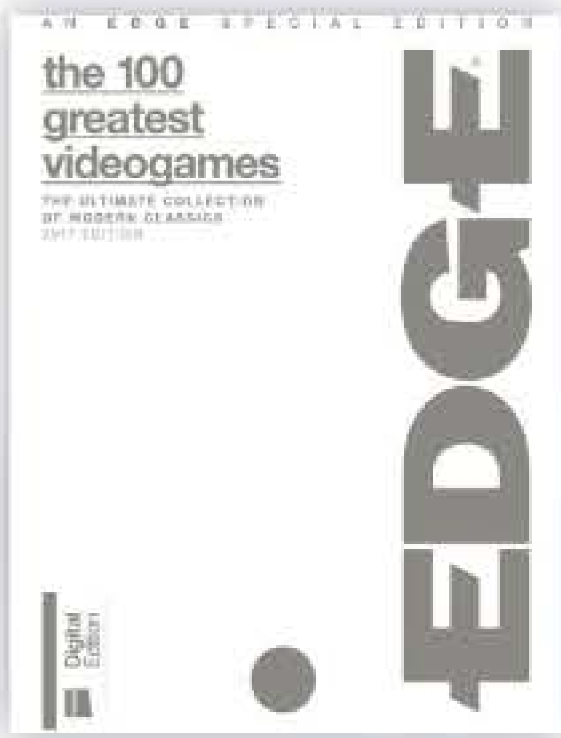

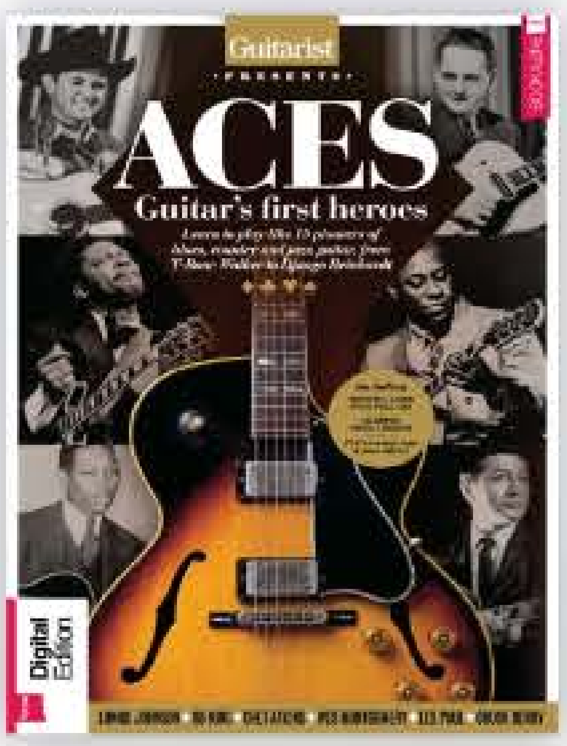

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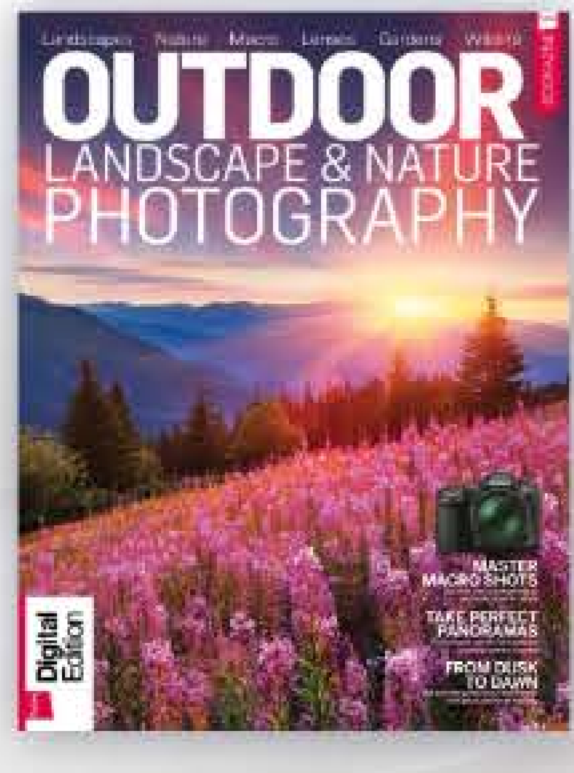

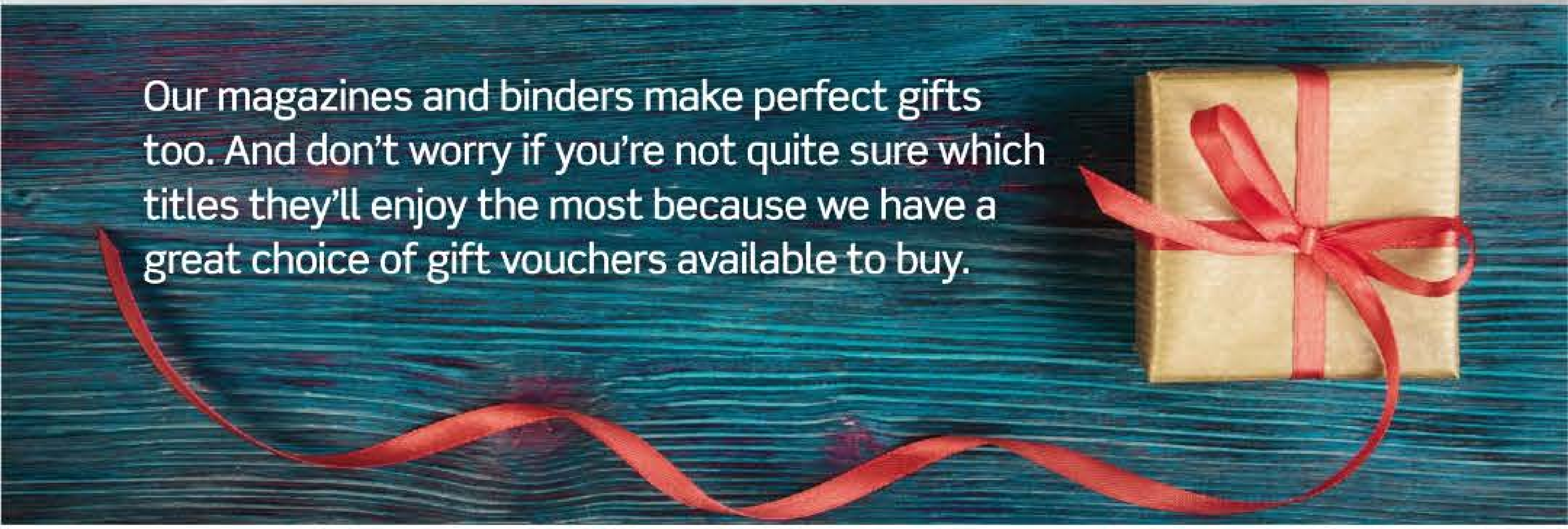

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